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Lake Huron Intensive Survey, 1980

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16. ABSTRACT

The 1980 study of Lake Huron was designed to provide extensive temporal and areal coverage of nutrient conditions throughout the lake. Water quality in Lake Huron was very good throughout most of the lake. This conclusion was based on an analysis of the spatial and temporal distribution of nutrients, chlorophyll, and particulate materials. Nutrient concentrations in Lake Huron were low compared to the other Great Lakes, and the annual ranges of nutrient concentrations were small; these two aspects of the limnolcgy of Lake Huron indicated an oligotrophic ecosystem.

Although the water quality in Lake Huron was characterized as very good, local, nearshore nutrient loadings produced occasional regions of poor water quality. These regions, which were primarily identified by high nutrient and/or chlorophyll concentrations, were both local in areal extent and short lived in duration. Regions of poor water quality in Lake Huron were not chronic, but rather occasional during periods of high river runoff, high algal productivity, etc. Some of these regions of poor water quality were: the Ontario shore of southern Lake Huron, the mouth of Saginaw Bay, and Thunder Bay. Water quality in the mouth of Saginaw Bay has improved since the last Lake Huron intensive survey.

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William Y. B. Chang
David C. Rockwell
Ann Arbor, February 1985

CHAPTER ONE

INTRODUCTION

Lake Huron was the subject of an intense limnological survey during the spring, summer, and fall of 1980. This binational study was undertaken by the United States and Canada to evaluate Lake Huron water quality throughout the ice-free seasons. This study was part of the Great Lakes surveillance program which included monitoring the five Great Lakes on a rotational basis. Lake Huron was last monitored in 1974-75. The surveillance program had four major objectives:

1. To determine the status of the open and nearshore waters of the Great Lakes and to compare the status with the standards, criteria, and objectives for the protection of aquatic life in the Great Lakes.
2. To provide data to characterize the chemical, physical, microbiological, and biological aspects of the environment against which future changes may be evaluated.
3. To compare present data with data collected in the past in order to determine if the Great Lakes are changing and how these changes may be occurring.
4. To determine how these changes are related to waste reduction and pollution abatement programs.

Two of these objectives are addressed at length in this report. These two objectives are: Comparison of current limnological conditions to historical conditions to identify long-term trends (objective 3); and identification of the extent of oligotrophic and eutrophicatic waters to locate areas impacted by pollutants (objective 4). Objective 4 is particularly important as a means of evaluating the improvement mitigating measures have had on Lake Huron water quality. This report deals with that aspect of the Lake Huron surveillance program concerning nutrient chemistry and physical-chemical variables. Included in this material is the distribution of chlorophyll biomass and the relationship of chlorophyll distribution to physical-chemical variables.

The Federal Water Pollution Control Act as amended in 1972 provides authority to the United States Environmental Protection Agency (USEPA) to conduct surveillance and monitoring of the Great Lakes. In practice, Great Lakes surveillance programs are binational efforts between the United States and Canada with the Great Lakes National Program Office of USEPA leading the effort for the United States. The authority for the Lake Huron study was from the same source as for the Lake Michigan intensive survey of 1976-77. This authority is detailed in the Lake Michigan intensive survey report (Rockwell *et al.* 1980).

The 1980 Lake Huron survey was conducted through several United States and Canadian research organizations. The results presented below were compiled by three organizations. The Great Lakes National Program Office (GLNPO) of USEPA and the Canada Centre for Inland Waters (CCIW) of the Canadian Department of the Environment conducted the open-lake sample collection and analysis. The Great Lakes Research Division (GLRD) of The University of Michigan assisted the USEPA in data analysis and report preparation. The results of the US-Canadian sampling and data analysis presented below are not the complete results from the 1980 surveillance program. Other results from the Lake Huron survey include: nearshore monitoring conducted by the Michigan Department of Natural Resources and the Ontario Ministry of the Environment, phytoplankton species enumeration and identification conducted by GLRD, GLNPO, and CCIW, zooplankton species enumeration and identification conducted by GLRD, trace metal analysis conducted by GLRD, and an intensive survey of Saginaw Bay conducted by USEPA Large Lakes Research Station at Grosse Ile, Michigan.

The importance of the Lake Huron 1980 study is enhanced when the international aspects of the lake are considered. As an international boundary, Lake Huron is jointly managed by the United States and Canadian governments. This management is implemented with guidelines set by the International Joint Commission (I.J.C.). The I.J.C. requires cooperative studies such as the Lake Huron survey to develop realistic recommendations for lake management as well as to provide information on the status of the Great Lakes. Thus, the surveillance program fills a dual role as an evaluation of the status of Lake Huron in 1980 and as a database for future management strategies. An additional aspect of the binational position of Lake Huron is that pollutants entering the system are likely to cross an international boundary. Whole lake surveillance provides one means of estimating this undesirable international exchange.

The design of the 1980 study allowed broad inferences of overall water quality in Lake Huron. But, the design has its limitations; and as a consequence, the inferences from this study are also limited. The most important limitation is that the 1980 study is only a one-year surveillance program. Observed seasonal trends from 1980 cannot be extrapolated to other years. Similarly, long-term trend analysis in water quality is not possible from a one-year study. This shortcoming has been somewhat alleviated by comparison of the 1980 data to a large historical database from previous Lake Huron studies. The reader is referred to the report by Rossmann and Treese (1981) for a complete bibliography of Lake Huron studies.

A further limitation of this study is the areal coverage provided by the station grid. Lake Huron, Georgian Bay, and the North Channel were sampled with a fairly coarse station grid. This study did not include Saginaw Bay, which is discussed in Smith *et al*. (1983). But, discharges from Saginaw Bay are a major factor affecting the water quality of southern Lake Huron. This report, while not considering the water quality in Saginaw Bay itself, does include the impact of Saginaw Bay water mixing into open Lake Huron.

CHAPTER TWO

CONCLUSIONS

Water quality in Lake Huron was very good throughout most of the lake during 1980. This conclusion was based on an analysis of the spatial and temporal distribution of nutrients, chlorophyll, and particulate materials. Nutrient concentrations in Lake Huron were low compared to the other Great Lakes, and the annual ranges of nutrient concentrations were small; these two aspects of the limnology of Lake Huron indicated an oligotrophic ecosystem.

Although the water quality in Lake Huron was characterized as very good, local, nearshore nutrient loadings produced occasional regions of poor water quality. These regions, which were primarily identified by high nutrient and/or chlorophyll concentrations, were both local in areal extent and short lived in duration. Regions of poor water quality in Lake Huron were not chronic, but rather occasional during periods of high river runoff, high algal productivity, etc. Some of these regions of poor water quality were: the Ontario shore of southern Lake Huron, the mouth of Saginaw Bay, and Thunder Bay. Water quality in the mouth of Saginaw Bay has improved since the last Lake Huron intensive survey. Remedial steps taken between 1974 and 1980 significantly reduced nutrient loads to lower Saginaw Bay (Dolan _et_ _al_. 1981). As a result, poor water quality in outer Saginaw Bay and adjacent Lake Huron was only occasionally observed during 1980. The effects of remedial measures in other locations of Lake Huron were not evident in 1980.

In addition to regions of high nutrient loadings, some regions received river runoff which was extremely low in nutrients and dissolved salts. In particular, rivers which drained the Canadian Shield into the North Channel and northern Georgian Bay had very low chloride and nutrient loads. The effect of these rivers was prevalent throughout much of northern Lake Huron during the spring thaw.

For nearshore areas, 1980 Secchi disk depths, total nitrogen, dissolved reactive silica, sulfate, and conductivity were greater than those reported for 1974. Conversely, the 1980 total phosphorus and chloride concentrations were less than those reported for 1974.

Within the open lake, 1980 total phosphorus and dissolved reactive silica were less and dissolved nitrate plus nitrite was greater than those reported for 1974. The decrease in total phosphorus followed a series of relatively colder winters. There was a 50% decrease in mean dissolved reactive silica and dissolved nitrate plus nitrite maximum depletions in 1980 relative to those of 1974. Thus Lake Huron's trophic status appears to have improved between 1974 and 1980.

A result of the 1974 and 1980 intensive studies of Lake Huron was the recognition that distinct zones or segments of differing water quality existed. After the 1974 study, Lake Huron was divided into 19 segments of somewhat homogeneous water quality in each segment (IJC 1976). The boundaries between these segments did not change among cruises or seasons. An alternative approach to segmentation was used with the 1980 data. Boundaries were based on analytical mathematical techniques and allowed to change among cruises. The results of the 1980 analysis showed that 19 distinct segments did not exist in Lake Huron. Rather, only six to nine homogeneous water masses were identified in the lake during each cruise, implying that fewer stations than those used in 1980 may adequately characterize Lake Huron. Furthermore, the distribution of those water masses varied considerably among cruises. This variation was linked to changes in the physical, including thermal, regime throughout the year. The overall inference from this analysis was that the physical environment in Lake Huron controlled the location of water masses, while biological events controlled the concentration of nutrients within each water mass. Because most biological processes were not measured during 1980, the inference that biological events controlled nutrient concentrations was somewhat speculative.

The inferences from the 1980 study were expanded by the inclusion of historical data from Lake Huron. The historical data included nutrient and physical measurements since 1954. These data were analyzed along with the 1980 results to determine if long-term trends of water quality exist in Lake Huron. The database was limited in the number of variables available for analysis and the annual coverage. Nonetheless, seven variables (conductivity, chloride, sulfate, soluble silica, nitrate plus nitrite, soluble reactive phosphorus, and total phosphorus) were analyzed for long-term trends ranging from 9 to 28 years. The annual range of historical data limited the analyses to spring and summer months only.

Long-term changes in the chemistry of Lake Huron waters have been identified using the results of twelve studies spanning a 26-year period of observations. As might be expected of a dynamic system lake, Lake Huron long-term trends can be complex. For roughly one-half of the parameters investigated, changes over the 26 years were curvilinear or oscillatory. Of these, one-half had a linear trend superimposed over the oscillations. For each of the various ways we manipulated the data base, sulfate and nitrate were found to increase. For the majority of cases, dissolved silica and chloride decreased. Sulfate increased at a rate of 0.05 to 0.13 mg/L/yr or 0.3 to 0.8% of the 1980 mean concentration per year. Nitrate increased at a rate of 0.0030 to 0.0089 mg/L/yr or 1.1 to 3.1% per year. Dissolved silica decreased at a rate of 0.040 to 0.049 mg/L/yr or 2.8 to 3.6% of the 1980 mean per year. Chloride decreased at a rate of 0.02 to 0.06 mg/L/yr or 0.4 to 1.2% of the 1980 mean per year. All four parameters should continue to be monitored.

For those parameters which showed reversals in trend over the period of observation, reversals consistently occurred in the mid-1970s. It is unfortunate that data were not available for this critical period of time. Since the mid-1970s, dissolved reactive silica and soluble reactive phosphorus have decreased, and nitrate and sulfate have increased. Changes in long-term trends could be or have been attributed to factors such as changes in sampling and analytical methods, reduction in anthropogenic inputs from the major point sources, and differences in biological utilization of these elements. Despite the changes which have occurred in Lake Huron between 1954 and 1980, Lake Huron is still an oligotrophic lake.

CHAPTER THREE

METHODS

by David C. Rockwell

One hundred thirty eight stations were sampled six times from 10 April through 8 November 1980 by the Great Lakes National Program Office (GLNPO) USEPA, Region V, and the Canada Centre for Inland Waters (CCIW). Two winter surveys of 11 stations each were conducted during 20-21 January and 24-25 February 1981 (stations 1, 3, 5, 7, 9, 10, 13, 15, 16, 19, and 21). The station locations are given in Figure 3.1 and latitudes, longitudes in Table 3.1. Cruise dates for each major lake segment are given in Table 3.2. Water column depths for each station are given in Table 3.3.

The sampling strategy conformed to the Great Lakes International Surveillance Plan (GLISP). In homothermous waters four depths were sampled: surface (1-m depth), mid-depth, bottom depth less 10 meters, and bottom depth less 2 meters. In thermally stratified waters the mid-depth sample was replaced by three samples: lower epilimnion (2 m above the upper knee), mid-thermocline, and upper hypolimnion (2 m below the lower knee). Where samples were less than 3 meters apart, one sample was omitted. Thus a minimum of four and a maximum of seven depths were sampled at each station.

The sampling platforms used were the R/V R. Simons on cruises one, two, and four; the CSS Limnos on cruises three, five, and six; and the US Coast Guard Cutter Bramble for the winter cruises.

Figure 3.2 is a flow chart of sample processing on the USEPA R/V R. Simons. Samples were collected by means of 8-L Niskin® water sampling bottles. An integrating sampler made by CCIW was used to sample the upper 20 meters for chlorophyll, particulate organic carbon, and particulate organic nitrogen.

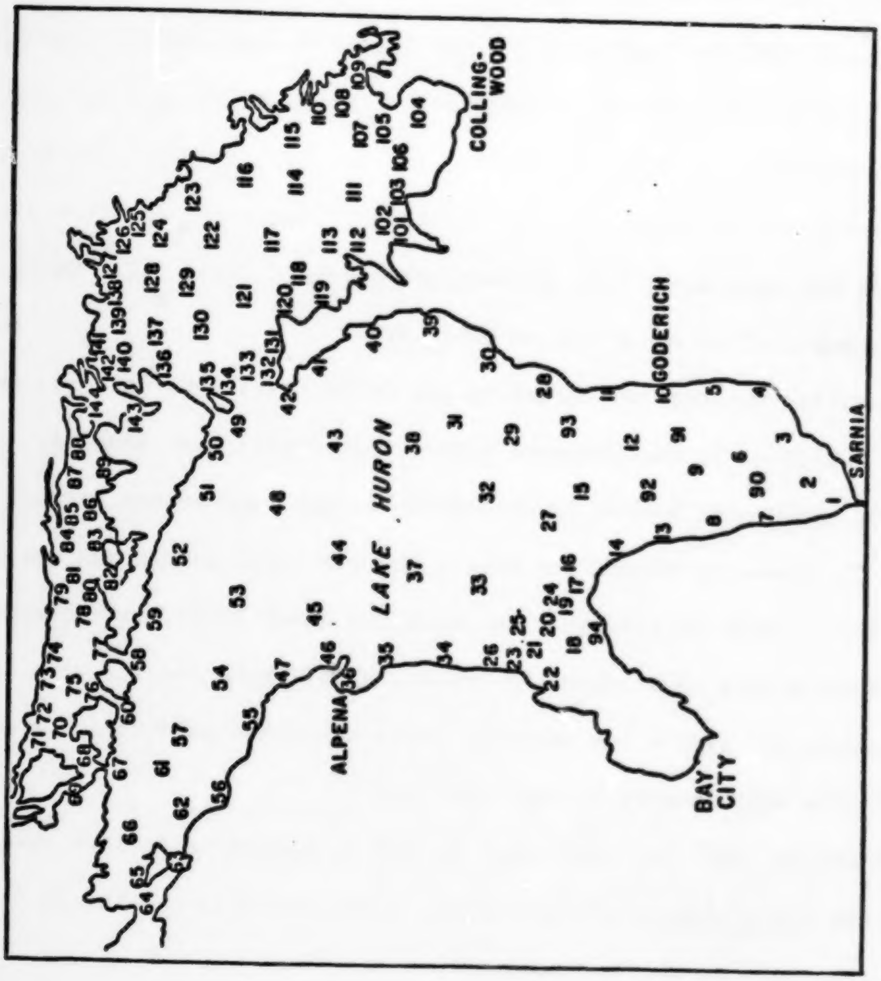

LAKE HURON
ALPENA
BAY CITY
SARNIA
GODERICH
COLLINGWOOD

Figure 3.1. Lake Huron surveillance stations, 1980.

Table 3.1. 1980 Lake Huron surveillance stations.

STATION NO.	CROSS REFERENCE	LATITUDE	LONGITUDE
1		43°05'24"	82°23'30"
2		43 11 24	82 17 54
3		43 15 25	82 02 18
4		43 19 30	81 47 16
5		43 32 54	81 44 42
6		43 28 00	82 00 00
90		43 24 00	82 18 00
7		43 20 30	82 30 24
8		43 34 00	82 29 06
9		43 38 00	82 13 00
91		43 42 00	82 01 00
10	Master	43 45 12	81 46 54
11		43 57 24	81 47 12
12		43 53 24	82 03 24
92		43 48 30	82 22 00
13		43 45 12	82 34 06
14		43 56 30	82 40 00
15		44 00 00	82 21 00
16	Master	44 07 54	82 45 00
17	HU 0050	44 06 00	82 52 00
18	SB 0051	44 07 25	83 10 15
19	HY 0049	44 09 00	82 58 00
20	HY 0048	44 13 00	83 05 00
21	HU 0047 Master	44 16 00	83 12 00
22	SB 0049	44 12 40	83 22 40
23	HY 0046	44 20 00	83 18 00
24	HU 0024	44 16 00	82 55 00
25	HU 0026	44 23 00	83 16 00
26	HU 0025 Master	44 20 00	83 05 00
27		44 11 54	82 30 12
28		44 12 18	81 40 36
93		44 06 00	82 07 00
29		44 22 00	81 50 00
30		44 28 00	81 27 12
31		44 51 00	81 36 00
32		44 27 12	82 20 30
33		44 30 00	82 50 00
34		44 38 24	83 13 54
35		44 51 00	83 15 42
36		45 02 06	83 22 42
37		44 45 42	82 47 00
38		44 44 24	82 03 36
39		44 39 24	81 22 42
40		44 53 54	81 26 12

(continued)

Table 3.1. Continued.

STATION NO.	CROSS REFERENCE	LATITUDE	LONGITUDE
41		45°05'00"	81°32'18"
42		45 13 18	81 49 12
43		45 00 48	82 00 30
44		45 01 00	82 41 06
45		45 08 12	82 59 00
94		44 04 15	83 05 00
46		45 04 48	83 14 00
47	Master	45 15 18	83 20 48
48		45 16 42	82 27 06
49		45 24 48	81 55 06
50		45 32 06	82 02 42
51		45 32 00	82 16 48
52		45 39 06	82 38 54
53		45 27 00	82 54 54
54		45 31 00	83 25 00
55		45 23 30	83 39 06
56		45 31 00	84 05 00
57		45 40 00	83 43 36
58		45 52 06	83 16 00
59		45 46 00	83 01 42
60		45 54 06	83 31 06
61		45 45 00	83 55 00
62		45 40 30	84 11 12
63		45 42 12	84 30 42
64		45 48 48	84 45 18
65		45 50 42	84 34 00
66		45 51 48	84 17 42
67		45 56 06	83 54 00

(Continued)

Table 3.1. Continued.

STATION NO.	CROSS REFERENCE	LATITUDE	LONGITUDE
1980 GEORGIAN BAY SURVEILLANCE STATIONS			
101		44°43'03"	80°51'24"
102		44 48 30	80 52 18
103		44 43 30	80 37 00
104	Master	44 38 45	80 10 00
105		44 47 48	80 14 36
106		44 44 12	80 26 06
107		44 53 20	80 17 50
108		44 57 10	80 08 06
109		44 52 18	79 58 05
110		45 03 45	80 11 28
111		45 55 15	80 36 21
112		44 55 12	80 52 30
113		45 01 36	80 52 36
114		45 08 20	80 31 24
115		45 10 00	80 17 48
116		45 21 13	80 29 12
117		45 14 42	80 52 30
118		45 09 10	81 04 03
119		45 04 00	81 15 14
120		45 13 00	81 13 36
121		45 21 54	81 11 24
122		45 28 50	80 50 15
123		45 33 35	80 36 38
124		45 40 44	80 50 20
125		45 46 40	80 45 15
126		45 50 00	80 54 00
127		45 52 00	81 00 00
128		45 42 12	81 05 24
129		45 35 00	81 05 00
130	Master	45 32 30	81 22 00
131		45 14 18	81 26 24
132		45 16 12	81 35 00
133		45 22 13	81 35 06
134		45 27 10	81 43 46
135		45 31 39	81 40 10
136		45 42 30	81 37 12
137		45 43 00	81 22 30
138		45 53 00	81 06 30
139		45 52 24	81 15 30
140		45 51 52	81 32 08
141		45 56 00	81 31 04
142		45 54 46	81 35 42
143		45 49 52	81 47 19
144		45 58 20	81 41 55

(Continued)

Table 3.1. Concluded.

STATION NO.	CROSS REFERENCE	LATITUDE	LONGITUDE
1980 NORTH CHANNEL SURVEILLANCE STATIONS			
68		46°02'30"	83°51'12"
69		46 04 42	84 01 42
70		46 08 12	83 40 18
71	Master	46 14 00	83 44 48
72		46 13 36	83 35 24
73		46 11 12	83 21 18
74		46 08 54	83 12 04
75		46 05 00	83 25 00
76		46 00 00	83 26 00
77		45 58 12	83 11 54
78		46 02 06	83 00 00
79		46 07 24	82 53 09
80		46 00 00	82 51 21
81		46 04 42	82 44 36
82		45 56 18	82 45 30
83		46 00 00	82 33 00
84	Master	46 05 30	82 33 24
85		46 06 00	82 25 30
86		46 00 18	82 23 18
87		46 03 40	82 11 50
88		46 03 20	82 00 00
89		45 55 00	82 09 40

Table 3.2. Cruise dates for Lake Huron study.

Cruise Number	Dates 1980	Average Julian Day
Cruise One		
Lake Huron		
Southern Basin	13-15 April	104
Northern Basin	15-20 & 23 April	108
North Channel	20-21 April	110
Georgian Bay	24-27 April	116
Cruise Two		
Lake Huron		
Southern Basin	10-11 May	130
Northern Basin	11-16 May	133
North Channel	16-17 May	136
Georgian Bay	18-21 May	140
Cruise Three		
Lake Huron		
Southern Basin	28-29 May	148
Northern Basin	29 May-4 June	152
North Channel	4-5 June	156
Georgian Bay	5-7 June	157
Cruise Four		
Lake Huron		
Southern Basin	18-19 July	200
Northern Basin	20-25 July	203
North Channel	25-27 July	207
Georgian Bay	27-30 July	210
Cruise Five		
Lake Huron		
Southern Basin	8-11 Sept.	252
Northern Basin	11-15 Sept.	256
North Channel	15-16 Sept.	258
Georgian Bay	16-21 Sept.	261

(Continued)

Table 3.2. Concluded.

Cruise Number	Dates 1980	Average Julian Day
Cruise Six		
Lake Huron		
Southern Basin	22-27 Oct.	298
Northern Basin	27-31 Oct.	302
North Channel	31 Oct.-1 Nov.	304
Georgian Bay	2-4 Nov.	307
	Dates 1981	
Winter Cruise One		
Lake Huron		
Southern Basin	20-21 Jan.	20
Winter Cruise Two		
Lake Huron		
Southern Basin	24-25 Feb.	56

Table 3.3. Depth in meters of permanent stations sampled in Lake Huron 1980 surveillance study.

Station Number	Cruise One	Cruise Two	Cruise Three	Cruise Four	Cruise Five	Cruise Six
01	11.5	11.5	10.5	12.0	11.0	11.0
02	23.5	23.75	23.0	24.0	24.0	24.0
03	19.0	15.5	14.0	16.0	14.0	13.0
04	11.0	10.25	10.0	11.0	9.5	10.0
05	12.5	12.5	12.0	13.0	11.0	11.5
06	51.0	52.0	51.5	53.0	52.0	51.5
07	10.0	9.5	11.0	11.0	12.0	12.5
08	25.5	27.5	30.0	27.0	30.5	30.0
09	54.0	60.0	59.0	63.0	61.0	59.0
10	12.0	11.5	12.0	11.0	12.5	13.0
11	10.0	11.0	10.5	8.0	11.0	10.5
12	84.0	88.0	87.0	85.0	88.0	87.5
13	11.5	15.0	17.5	25.0	18.0	17.0
14	12.2	14.0	13.5	21.0	14.0	13.0
15	64.5	67.0	66.5	68.0	68.0	67.0
16	46.0	54.0	47.0	51.0	48.0	48.0
17	15.0	25.0	15.0	17.0	15.0	15.5
18	26.	29.5	28.5	32.0	29.0	29.0
19	31.0	41.0	35.0	35.0	36.0	35.0
20	45.0	51.0	46.0	51.0	46.0	46.0
21	40.0	45.0	41.0	44.0	42.0	41.0
22	18.0	20.0	20.5	22.0	21.0	21.0
23	13.0	14.75	10.5	11.0	12.5	12.0
24	64.0	65.5	62.0	63.0	63.0	62.0
25	10.5	11.75	12.0	14.0	14.0	13.0
26	57.0	45.0	58.0	52.0	57.0	58.0
27	61.0	57.0	56.0	53.0	56.0	55.0
28	—	28.0	17.0	19.0	18.5	19.0
29	123.0	124.0	119.0	113.0	125.0	122.0
30	30.0	20.0	20.0	22.0	23.5	21.0
31	—	89.5	86.0	100.0	88.0	86.0
32	79.0	80.0	80.0	82.0	81.0	80.0
33	—	72.0	55.0	73.0	73.0	73.0
34	11.0	10.0	11.0	12.0	10.5	10.0
35	15.0	15.0	18.0	16.0	20.5	16.0
36	13.0	10.5	10.0	9.0	11.0	10.5
37	76.0	76.0	74.0	78.0	75.0	72.0
38	—	138.0	134.0	144.0	136.0	134.0
39	28.0	30.0	27.2	33.0	29.0	30.0
40	—	21.5	20.0	29.0	22.5	20.5

(Continued)

Table 3.3. Continued.

Station Number	Cruise One	Cruise Two	Cruise Three	Cruise Four	Cruise Five	Cruise Six
41	17.0	29.5	20.0	22.0	21.0	23.0
42	50.0	34.0	42.5	45.0	38.0	40.0
43	144.0	170.0	176.0	172.0	182.0	182.0
44	161.0	166.0	164.0	166.0	164.0	164.0
45	74.0	74.0	101.0	78.0	102.0	111.0
46	12.0	14.0	13.0	15.0	13.0	13.0
47	15.0	21.5	23.5	12.0	20.0	23.0
48	109.0	104.0	111.0	110.0	111.0	110.0
49	45.0	47.5	49.0	55.0	45.5	48.0
50	30.0	44.0	29.0	31.0	29.5	29.0
51	63.0	73.0	63.0	65.0	65.0	64.0
52	64.0	75.0	65.0	65.0	67.0	66.0
53	93.0	83.0	90.0	86.0	92.0	91.0
54	129.0	122.0	118.0	125.0	110.0	115.0
55	15.0	23.0	15.0	10.0	21.0	22.5
56	19.0	18.5	24.0	27.0	22.5	22.0
57	108.0	122.0	132.0	122.0	126.0	130.0
58	33.0	56.5	13.0	38.0	15.5	56.5
59	22.0	36.0	18.0	24.0	20.5	19.0
60	31.0	34.0	30.0	28.0	24.5	38.5
61	112.0	117.0	118.0	116.0	117.0	116.0
62	45.0	46.0	46.0	47.0	45.0	45.0
63	13.0	13.0	16.5	14.0	16.0	16.0
64	15.0	11.0	55.5	39.0	48.0	52.0
65	48.0	50.0	59.0	51.0	61.0	60.0
66	66.0	70.0	70.0	71.0	70.0	69.0
67	43.0	38.0	29.0	32.0	33.5	33.5
68	10.0	11.5	17.0	18.0	16.0	17.0
69	15.0	7.5	11.7	15.0	10.5	11.0
70	20.0	22.0	22.5	23.0	22.5	22.0
71	33.0	32.0	36.0	35.0	36.0	34.0
72	37.0	39.0	23.5	27.0	25.5	28.0
73	23.0	22.0	19.5	19.0	19.0	20.0
74	13.0	14.0	13.0	14.0	14.5	13.0
75	49.5	45.0	45.7	47.0	50.0	50.0
76	52.0	56.5	58.0	59.0	60.0	60.0
77	35.0	77.0	78.0	75.0	78.0	79.0
78	—	46.0	45.0	47.0	47.0	46.0
79	—	25.0	28.0	28.0	25.0	27.0
80	—	40.0	40.0	41.0	41.5	39.5

(Continued)

Table 3.3. Continued.

Station Number	Cruise One	Cruise Two	Cruise Three	Cruise Four	Cruise Five	Cruise Six
81	—	32.5	32.5	34.0	33.0	33.0
82	—	25.0	30.0	29.0	30.0	25.5
83	—	32.5	31.0	31.0	31.0	32.0
84	—	36.0	36.0	37.0	37.0	36.0
85	—	20.0	29.5	30.0	32.0	27.0
86	—	30.0	29.5	18.0	30.0	30.0
87	—	31.5	46.0	36.0	48.0	33.0
88	—	31.0	25.0	33.0	33.0	32.5
89	—	31.0	40.0	45.0	42.0	40.0
90	33.5	42.5	42.5	43.0	43.0	42.5
91	71.0	78.5	78.5	90.0	82.0	78.0
92	59.0	62.5	62.0	65.0	63.5	62.5
93	83.0	89.5	88.5	88.0	89.0	89.0
94	13.2	20.0	14.5	20.0	15.0	14.5
101	90.0	90.0	90.0	89.0	91.0	90.0
102	96.0	95.0	91.5	95.0	95.0	95.0
103	31.0	31.0	34.0	26.0	33.0	34.0
104	59.0	58.0	58.0	59.0	57.0	57.0
105	53.0	59.0	60.0	60.0	61.0	60.0
106	79.0	89.5	88.5	88.0	88.0	85.0
107	68.0	65.0	67.0	65.0	67.0	67.0
108	46.0	42.0	53.0	52.0	52.0	53.0
109	—	41.0	29.0	43.0	32.5	31.0
110	45.0	36.0	51.0	38.0	58.5	52.0
111	48.0	57.0	62.0	57.0	66.5	58.5
112	86.0	89.0	87.0	90.0	91.0	89.0
113	70.0	75.0	74.0	75.0	74.0	74.0
114	58.0	69.0	70.0	69.0	69.0	69.0
115	37.0	48.0	32.6	30.0	36.0	40.5
116	26.0	26.5	24.0	27.0	33.0	24.0
117	80.0	79.0	78.0	79.0	79.0	79.0
118	97.0	95.0	96.0	86.0	97.0	96.0
119	47.0	49.5	54.0	55.0	56.0	56.0
120	139.0	138.0	136.0	136.0	138.0	136.0
121	88.0	87.0	87.0	91.0	87.5	86.0
122	44.0	46.0	46.0	47.0	46.0	45.0
123	16.0	17.5	17.0	17.0	20.0	15.5
124	36.0	10.0	40.0	41.0	41.0	41.0
125	15.0	15.0	14.7	18.0	17.0	14.0
126	20.0	22.0	25.5	19.0	15.0	26.0

(Continued)

Table 3.3. Concluded.

Station Number	Cruise One	Cruise Two	Cruise Three	Cruise Four	Cruise Five	Cruise Six
127	17.0	19.0	19.0	19.0	21.0	19.0
128	42.0	39.0	52.5	39.0	48.0	47.0
129	44.0	42.5	42.5	44.0	44.0	43.5
130	63.0	64.0	59.0	65.0	62.0	61.0
131	122.0	116.0	65.0	136.0	62.0	57.0
132	107.0	105.0	112.0	105.0	110.0	104.0
133	56.0	55.0	48.0	55.0	55.0	54.0
134	42.0	42.0	48.0	50.0	50.0	48.0
135	36.0	38.0	35.0	36.0	33.0	35.0
136	44.0	45.0	56.0	45.0	55.0	55.5
137	48.0	47.0	46.5	48.0	47.0	48.0
138	23.0	24.0	23.0	28.0	23.0	23.0
139	25.0	29.5	27.0	25.0	27.5	27.0
140	32.0	29.0	31.5	33.0	32.5	32.0
141	20.0	24.0	22.7	23.0	23.0	22.0
142	22.0	26.0	20.0	23.0	20.0	27.0
143	25.0	28.0	26.0	27.0	27.0	27.0
144	41.0	43.0	40.5	40.0	41.0	41.0

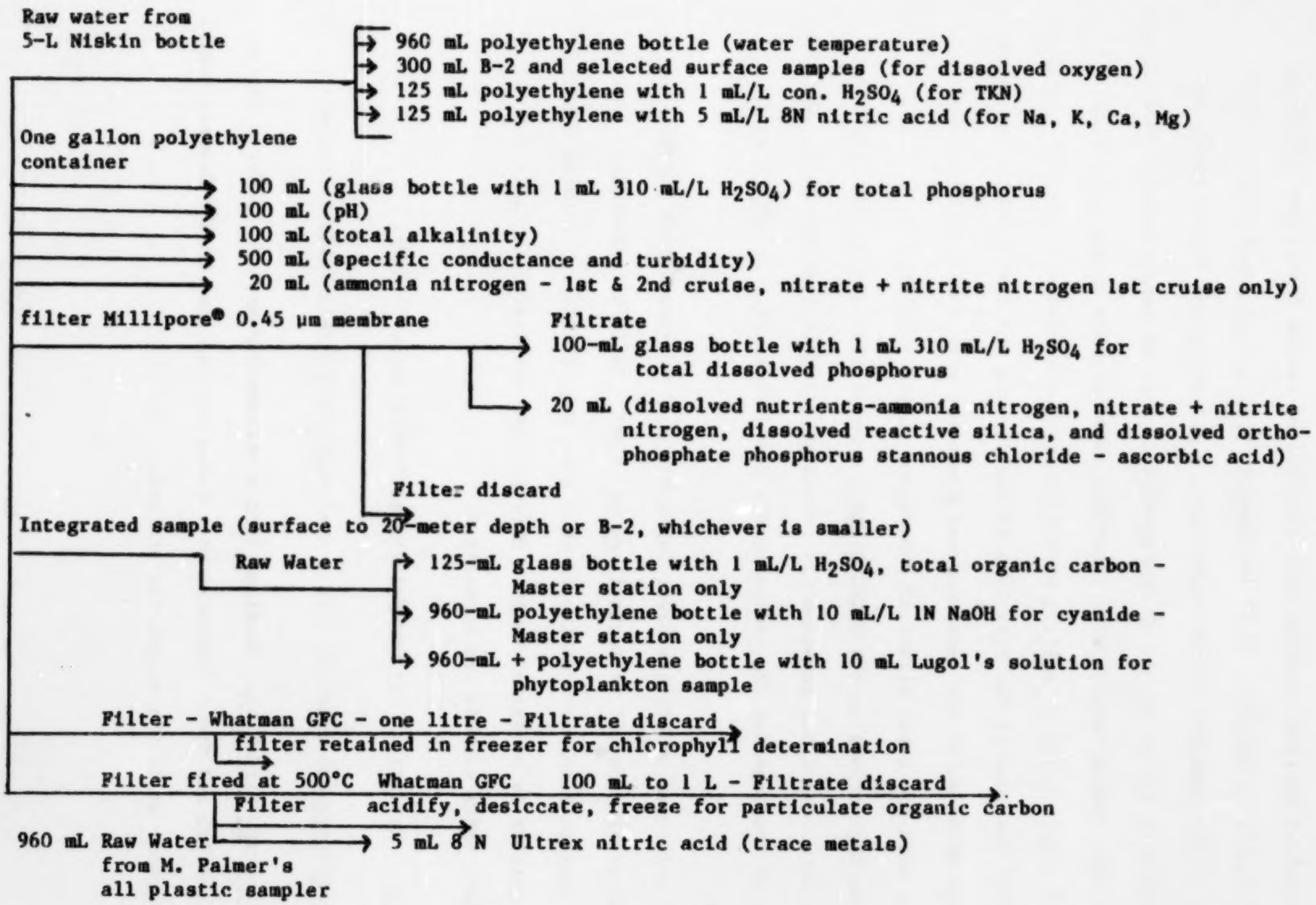

Raw water from
5-L Niskin bottle
960 mL polyethylene bottle (water temperature)
300 mL B-2 and selected surface samples (for dissolved oxygen)
125 mL polyethylene with 1 mL/L con. H_2SO_4 (for TKN)
125 mL polyethylene with 5 mL/L 8N nitric acid (for Na, K, Ca, Mg)
One gallon polyethylene
container
100 mL (glass bottle with 1 mL 310 mL/L H_2SO_4) for total phosphorus
100 mL (pH)
100 mL (total alkalinity)
500 mL (specific conductance and turbidity)
20 mL (ammonia nitrogen - 1st & 2nd cruise, nitrate + nitrite nitrogen 1st cruise only)
filter Millipore® 0.45 µm membrane
Filtrate
100-mL glass bottle with 1 mL 310 mL/L H_2SO_4 for total dissolved phosphorus
20 mL (dissolved nutrients-ammonia nitrogen, nitrate + nitrite nitrogen, dissolved reactive silica, and dissolved orthophosphate phosphorus stannous chloride - ascorbic acid)
Filter discard
Integrated sample (surface to 20-meter depth or B-2, whichever is smaller)
Raw Water
125-mL glass bottle with 1 mL/L H_2SO_4, total organic carbon - Master station only
960-mL polyethylene bottle with 10 mL/L 1N NaOH for cyanide - Master station only
960-mL + polyethylene bottle with 10 mL Lugol's solution for phytoplankton sample
Filter - Whatman GFC - one litre - Filtrate discard
filter retained in freezer for chlorophyll determination
Filter fired at 500°C Whatman GFC 100 mL to 1 L - Filtrate discard
Filter acidify, desiccate, freeze for particulate organic carbon
960 mL Raw Water
from M. Palmer's
all plastic sampler
5 mL 8 N Ultrex nitric acid (trace metals)

Figure 3.2. Flow Chart illustrating sample processing on USEPA's R/V R. Simons - Lake Huron 1980.

Dissolved nutrient samples were prepared by vacuum filtration within an hour of sample collection. A 47-mm diameter 0.45 μ Millipore® filter (HAWP) held in a polycarbonate filter holder with a polypropylene filter flask was prewashed with 100 to 200 mL of demineralized water or sample water. New 125-mL polyethylene sample bottles with linerless closures were rinsed once with filtered sample prior to filling with filtrate for subsequent nutrient analyses. An aliquot was removed for dissolved orthophosphate and dissolved silica determinations after which the remainder was preserved with 1 mL/L concentrated sulfuric acid for total dissolved phosphorus determinations.

Sampling methods on the USCGC Bramble were similar except that Niskin® bottles were loaded and subsequently retrieved directly from the deck. Sampling methods on the Canadian CSS Limnos used a Rosette® sampler to obtain water samples.

Methods used by USEPA's Great Lakes National Program Office (GLNPO) can be found in greater detail in Rockwell et al. 1980. Table 3.4 provides a listing of the variables measured during cruises one, two, and four. A brief overview of the methods is presented below. CCIW methods are listed in Table 3.5 and compatible USEPA methods are summarized.

Aesthetic. Reports of any unusual visual conditions were made.

Air Temperature was measured with a dial scale bimetallic helix thermometer.

Wind Speed and Direction. Readings from a permanently mounted Danforth Marine Wind Direction and Speed Indicator were taken and recorded to the nearest degree and mile/hour while the vessel was stopped.

Table 3.4. Summary of Lake Huron methods. Cruises one, two, four, and winter cruises.

Parameter	Cruise Number	STORET	Method	Readability or Estimated Precision
Air Temperature		00020	Shaded Bimetallic Dial Thermometer	0.26°C
Wind Speed		00035	Danford Wind Speed Indicator	3 knots + 20%
Wind Direction		00040	Danford Wind Direction Indicator	15°
Secchi Depth		00078	30-cm Diam. All White Disc	5%
Wave Height		70222	Valley to Crest Estimate	30%
Water Temperature		00010	Mercury Thermometer	0.1°C
Optical Transmittance		00074	Martek In Situ Probe	5%
Turbidity		00076	Turner Designs Nephelometer	0.1 + 20%
Specific Conductance		00096	Barnstead PM70-CB at 25°C	1 µmho/cm
Dissolved Oxygen		00300	Winker (Azid Modification)	0.5 mg/L
pH		00400	Orion 701 with Automatic Temp. Comp.	0.01
Total Alkalinity		00410	Titration, pH 4.5 End-Point	1 mg/L
Total Ammonia Nitrogen	1	00610	*Berthelot Reaction	0.5 µg/L
Total Nitrate + Nitrite N	1	00630	*Cadmium Reduction, Azo Dye Formation	0.01 mg/L
Total Phosphorus	2	00665	*Persulfate Digest, 10 mL Ascorbic Acid	0.15 µg/L
Total Dissolved Phosphorus	2	00666	*0.45 µm Membrane Filter, Same As Above	0.5 µg/L
Dissolved Orthophosphate P	2	00671	*0.45 µm Membrane, Ascorbic Acid	0.2 µg/L
Metals	3		AA Spectroscopy, Using Method of Standard Additions	
Total Chloride		00940	*Ferric Thiocyanate	0.1 mg/L
Total Sulfate		00945	*Methyl Thymol Blue	0.1 mg/L
Dissolved Reactive Silica		00955	*Ascorbic Acid, Molybdate, Oxalic Acid	0.01 mg/L
Chlorophyll a		32209	Glass Fiber Filter, 5 PSI Vacuum	0.01 µg/L
Pheophytin a		32213	Turner Model 430 Spectrofluorometer	0.01 µg/L

*Technicon Autoanalyzer II method

1. Cruise one only
2. Cruise one and winter cruises
3. Cruises one, two, and four

Table 3.5. The Canadian *CSS Limnos* was used on cruises three, five, and six. During these cruises samples for the following parameters were collected and are code referenced to the STAR Dictionary of Analytical Methods and Units. On cruises one, two, and four where the *R/V Simons* was used and methods were compatible, the STAR Code is also referenced in the Table.

Code	Parameter Description	Cruises Used
1	Depth	1, 2, 3, 4, 5, 6
30	Secchi Disc Depth	1, 2, 3, 4, 5, 6
31	Forel ULE Secchi Disc Color	3, 5, 6
100	Temperature of Water	3, 5, 6
104	Temperature EBT	1, 2, 3, 4, 5, 6
124	Transparency (Percent)	3, 4, 5, 6
160	Specific Conductance at 25°C	3, 5, 6
213	pH	1, 2, 3, 4, 5, 6
218	pH Temperature	3, 5, 6
223	Total Filtered Alkalinity	3, 5, 6
225	Integrated Particulate Organic Carbon	1, 2, 3, 4, 5, 6
238	Integrated Dissolved Organic Carbon	4
245	Dissolved Oxygen Concentation	1, 2, 3, 4, 5, 6
247	% Saturation of Dissolved Oxygen	1, 2, 3, 4, 5, 6
254	Total Kjeldahl Nitrogen (Not Filtered)	1, 2, 3, 4, 5, 6
260	Total Phosphorus	1, 2, 3, 4, 5, 6
263	Dissolved Orthophosphorus	1, 2, 3, 4, 5, 6
264	Total Filtered Phosphorus	1, 2, 3, 4, 5, 6
267	Integrated Total Particulate Nitrogen	1, 2, 3, 4, 5, 6
270	Soluble Ammonia - N.	1, 2, 3, 4, 5, 6
276	Soluble Nitrate + Nitrite - N.	1, 2, 3, 4, 5, 6
295	Soluble Reactive Silica	1, 2, 3, 4, 5, 6
613	Integrated Chlorophyll *a* Uncorrected	1, 2, 3, 4, 5, 6
614	Integrated Chlorophyll *a* Corrected	1, 2, 3, 4, 5, 6
703	Coliform Fecal MF	1, 5
706	Streptococci Fecal MF	1, 5
709	*Pseudomonas aeruginosa*	1, 5
720	Aerobic Heterotrophs - Standard Plak Count	1, 5
722	Total Micro Colonies Flores Count	1, 5

Secchi Disc Depth was estimated at each station on all cruises by use of a standard 30-cm, all-white Secchi disc.

Wave Height. Average wave height (valley to crest distance) was estimated at each station by the senior crew member on the bridge.

Surface Water Temperature was determined by use of a mercury thermometer with 0.1°C divisions.

Temperature and Light Transmission Profiles. Vertical profiles were determined at each station from surface to bottom with a Martek® Model EBT/XMS electronic bathythermograph/transmissometer with a 1-meter folded light path.

Turbidity. Turbidity was measured with a Turner Designs® digital nephelometer within 2 hours of sample collection.

Specific Conductance. Specific conductance was measured at 20°C within 2 hours of sampling using a Barnstead® Model PM70CB conductivity bridge and a micro conductivity cell (VSI 3403, K=1.0).

Dissolved Oxygen. Dissolved oxygen was measured on water samples from selected stations on some cruises. Analyses were made by the azid modification of the Winkler test (EPA 1974) or by a probe which was calibrated daily against the Winkler method.

pH. pH analyses were made by electrometric measurement within 15 minutes of sample collection. Readings were recorded to the nearest 0.01 pH unit from an Orion® Model 701 pH meter equipped with an automatic temperature compensation probe and combination glass membrane with a silver/silver chloride internal electrode element.

Total Alkalinity as $CaCO_3$. Total alkalinity was determined within 2 hours of sampling by titration of a 100-mL aliquot to pH 4.5 with 0.02 N H_2SO_4.

Total Ammonia Nitrogen. Total ammonia nitrogen analyses were performed with a Technicon Autoanalyzer System II using a modification of Technicon's Industrial Method 154-71W/Tentative (Hiller and Van Slyke 1933).

Total Nitrate and Nitrite Nitrogen. A Technicon® Autoanalyzer was used with Technicon's Industrial Method No. 158-71W (Armstrong et al. 1967).

Dissolved Orthophosphate. Samples were analyzed for orthophosphate using a Technicon® Autoanalyzer System II and Technicon's® Industrial Method 155-71W (Murphy and Riley 1962).

Total Phosphorus and Total Dissolved Phosphorus. Conversion of the various forms of phosphorus to orthophosphate was by an adaptation of the acid persulfate digestion method (Gales et al. 1966). The resulting orthophosphate was determined by the Technicon® Autoanalyzer System II and Technicon's® Industrial Method 155-71W (Murphy and Riley 1962).

Chloride. A Technicon® Autoanalyzer System II was used with Technicon's® Industrial Method No. 99-70W (Zall et al. 1956, O'Brien 1962).

Sulfate. Samples were analyzed for sulfate with a Technicon® Autoanalyzer using Technicon's® Industrial Method 118-71W (Lazrus et al. 1965).

Dissolved (Reactive) Silica. A Technicon® Autoanalyzer System II was used with Technicon's® Industrial Method No. 186-72W/Tentative.

Chlorophyll "a" and Phaeophytin. Samples for chlorophyll (100 mL to 500 mL) were analyzed using a Turner® Model 1430 dual monochromator spectrofluorometer (Strickland and Parsons 1972).

Quality Assurance Used by GLNPO. Data quality assurance, evaluation, and control were achieved by techniques given in detail in Rockwell et al. 1980. In brief, quality assurance consisted of check standards, reagent blanks, duplicate samples, split samples, and performance evaluation samples (unknowns). Maximum permissible shelf life was indicated for each analysis, and no data were taken from samples whose shelf life exceeded this value. The results of field split samples are given in Table 3.6.

Data Base. Lake Huron was sampled extensively during 1980 by the U. S. Environmental Protection Agency (USEPA) and the Canada Centre for Inland Waters (CCIW). The data from the 138-station network are available from STORET, the CCIW data management group, or The University of Michigan. All nutrient data (TP, TDP, DRP, soluble NH_4, soluble $NO_2 + NO_3$, soluble SIO_2) were performed by chemists from CCIW on all cruises.

Table 3.6. Differences between split sample analyses.

Parameter	Number of Splits	Mean Absolute Value of Differences	Standard Deviation of Differences
Temperature (°C)	176	0.0057	0.041
Turbidity (HTU)	180	0.100	0.348
Specific Conductance (µmho/cm)	186		
pH (SU)	182	0.0437	0.223
Total Alkalinity (mg/L)	184		
Dissolved Ammonia (µg/L)	76	0.39	0.69
Total Ammonia (µg/L)	118	0.63	2.09
Total Nitrate + Nitrite (mg/L)	50	0.0035	0.0061
Dissolved Nitrate + Nitrite (mg/L)	88	0.0031	0.0051
Dissolved Reactive Phosphorous (µg/L)	266	0.18	0.65
Chloride (mg/L)	52	0.10	0.15
Total Sulfate (mg/L)	54	0.17	0.31
Dissolved Reactive Silica (mg/L)	92	0.012	0.014

CHAPTER FOUR

DESCRIPTIVE LIMNOLOGY OF LAKE HURON

by Russell Moll

The 1980 study of Lake Huron was designed to provide extensive temporal and areal coverage of nutrient conditions throughout the lake. The sampling grid included 138 stations positioned in a low density pattern of approximately one station per 100 km^2 (see Fig. 3.1). This grid was arranged such that in the open lake regions stations were located approximately 10 km apart. In nearshore regions, the North Channel, parts of Georgian Bay, and the mouth of Saginaw Bay the density of stations was twice as high as offshore, and the station pattern was somewhat irregular to accommodate the complex shoreline. Stations located in the mouth of Saginaw Bay were also at twice the density (one station/50 km^2) of the rest of Lake Huron. This high density was designed to monitor the exchanges of material between the bay and the open lake. A separate sampling program was conducted in Saginaw Bay and is reported by Smith _et al_. (1983). Several stations were situated to monitor exchanges and/or inputs of materials into Lake Huron. Some of these locations were: the Detour Passage, the False Detour Passage, Mississagi Strait, the Straits of Mackinaw region, and the mouths of Georgian Bay and Saginaw Bay.

Lake Huron was sampled during six cruises in 1980: April, May, June, July, September, and November. Two winter cruises were conducted in January and February 1981. The arrangement of these cruises was designed to provide data throughout the entire thermal cycle of one summer, i.e., from spring homothermous conditions through fall overturn to winter homothermous conditions.
A major objective of this study was to develop accurate estimates of nutrient

conditions throughout Lake Huron just before thermal stratification (either thermocline formation or thermal bar formation). Cognizant of this objective, the cruise schedule was developed with the majority of the cruises occurring during the spring homothermous or thermal bar periods.

The experimental design of this study was developed to yield the largest amount of information about areal and temporal nutrient distributions. The vertical distribution of nutrients was somewhat less intensely measured than the areal distribution. From four to seven depths were sampled at each station. Sampling depths always included a 1-m sample, a mid-water column sample, and two near-bottom samples. During periods of thermal stratification, samples were collected in the lower epilimnion, mid-metalimnion, and near the top of the hypolimnion in addition to the four depths mentioned above. This sampling program provided good but not detailed information about the vertical distribution of nutrients. Samples for chlorophyll, particulate organic carbon, and particulate organic nitrogen were collected with a system which provided one integrated sample from the surface to 20-m depth. More detail on the sampling program can be found in Chapter Two, while the analytical methods are given in Rockwell et al. (1980).

The sampling program included a complete suite of most dissolved and particulate nutrients, conservative ions, and particulate matter (Table 4.1). The complete sampling program for Lake Huron in 1980 included measurement of many variables in addition to nutrients, such as metals, organics, and plankton. This report is confined to the consideration of nutrients and related variables. But, because dissolved nutrient distributions are an important criterion in determining trophic status of lakes (Likens 1972), the inferences developed

Table 4.1. Chemical and physical variables measured during 1980 Lake Huron study.

Alkalinity
Ammonia
Chlorophyll
Dissolved Oxygen
Kjeldahl Nitrogen
Particulate Organic Carbon
Particulate Organic Nitrogen
pH
Secchi Depth
Soluble Nitrate-Nitrogen
Soluble Reactive Phosphorus
Soluble Reactive Silica
Specific Conductance
Temperature
Total Filterable Phosphorus
Total Phosphorus
Transmissivity
Turbidity

from analysis of the nutrient conditions have important implications for the entire ecosystem.

Thermal Cycle

The thermal cycle in the Great Lakes has a very large effect on the overall distribution of nutrients and biota (Ragotzkie 1978, Csanady 1978). Each thermal season produces a different mixing regime and hence distribution of dissolved and suspended materials (Boyce 1974, Scavia and Bennett 1980). The 1980 Lake Huron study covered the three thermal seasons typically observed in the Great Lakes; homothermous, thermal bar, and thermal stratification (Fig. 4.1).

Cruise one (April) was conducted during inverse thermal stratification. Surface water temperatures were below 4°C at almost all locations, with the lake-wide mean water temperature 2.2°C (Table 4.2). The surface (1-m) contour plots of temperature for the six cruises are shown in Figure 4.1.

The second cruise (May) was conducted during early thermal bar conditions. Figure 4.1 shows large areas of nearshore surface water which had warmed above 4°C, indicative of the onset of the thermal bar (Boyce 1974). Surface water temperatures increased between cruises one and two (Table 4.3), but the majority of Lake Huron was homothermous.

Cruise three was conducted during late May and early June when thermal bar conditions were at an advanced stage. Surface temperatures increased considerably in the three weeks between cruises two and three (Table 4.4). Surface temperatures were in excess of 4°C over most of open Lake Huron and all of Saginaw Bay, Georgian Bay, and the North Channel (Fig. 4.1). More than 80% of the stations sampled during cruise three had surface water temperatures

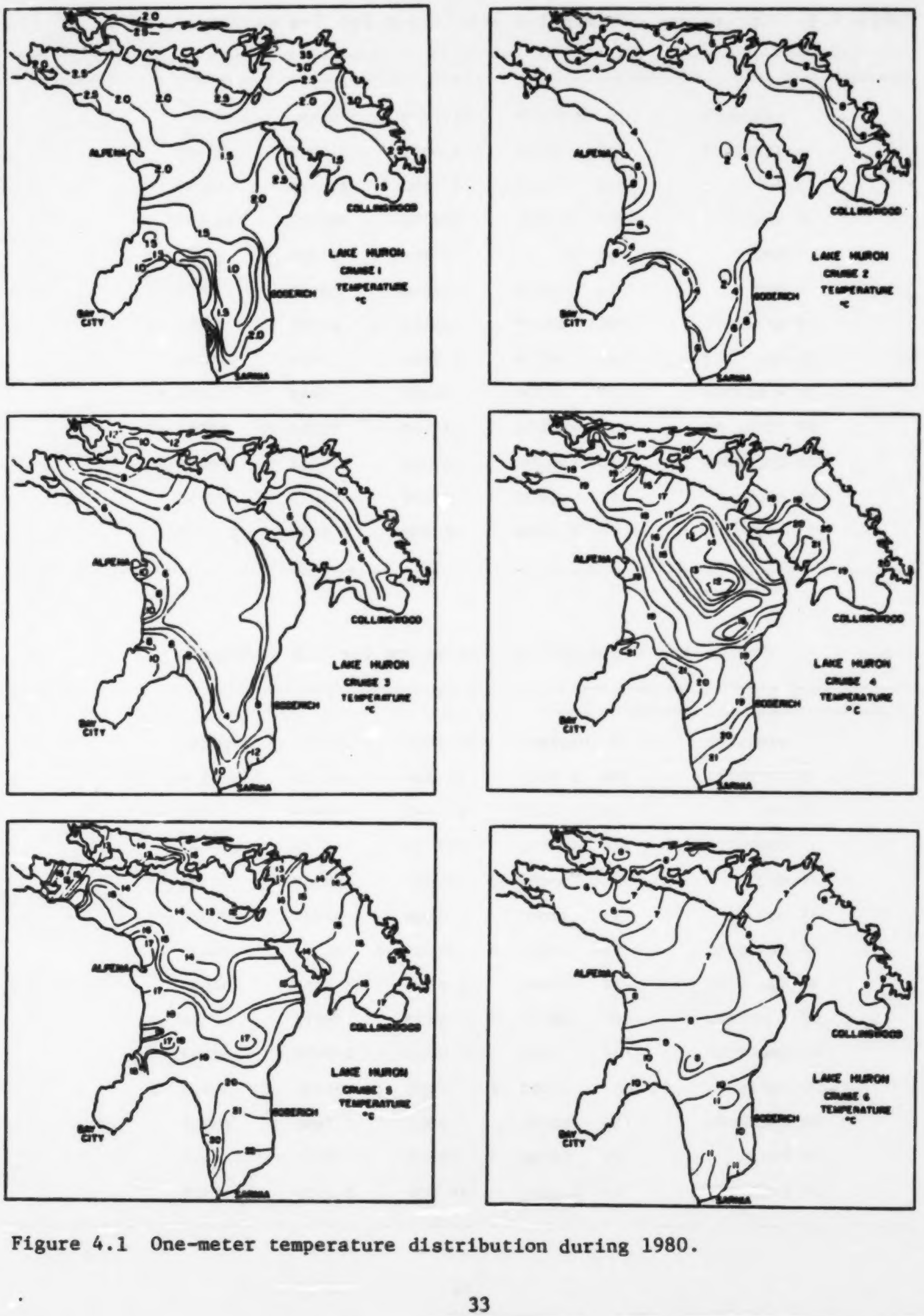

ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA
LAKE HURON
CRUISE 1
TEMPERATURE
°C
LAKE HURON
CRUISE 2
TEMPERATURE
°C
LAKE HURON
CRUISE 3
TEMPERATURE
°C
LAKE HURON
CRUISE 4
TEMPERATURE
°C
LAKE HURON
CRUISE 5
TEMPERATURE
°C
LAKE HURON
CRUISE 6
TEMPERATURE
°C

Figure 4.1 One-meter temperature distribution during 1980.

Table 4.2. Cruise one descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	122	.70000	8.0500	2.2247	.87189
9.PH	122	7.4400	8.4500	8.0148	.14050
11.CONDUCTI	122	94.000	245.00	193.05	22.851
17.NH3	105	0.	.44000 -1	.31333 -2	.51255 -2
18.NO3	122	.19500	47500	.28608	.40026 -1
19.ORTHO PO	106	.30000 -3	.35000 -2	.82547 -3	.41954 -3
20.SOL SIO2	122	.91000	2.4300	1.4533	.27340
21.K NITROG	113	.10700	.46300	.18848	.61875 -1
26.TOTAL P	113	.20000 -2	.24500 -1	.55080 -2	.27259 -2
28.CHLOROPH	113	.80000	10.000	1.6088	.96682
29.POC	113	.10600	.90400	.22512	.13153
31.SECCHI	71	1.0000	12.500	7.6986	2.7303

Table 4.3. Cruise two descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	138	2.0000	11.200	4.8123	2.2279
9.PH	138	7.4400	8.7200	7.9834	.17307
11.CONDUCTI	138	98.000	237.00	189.38	25.167
16.NH3	135	.10000 -2	.35000 -1	.25259 -2	.38765 -2
17.NO3	138	.18000	.70500	.27989	.52352 -1
18.ORTHO PO	138	.20000 -3	.39000 -2	.62319 -3	.36414 -3
19.SOL SIO2	138	.78000	2.6600	1.4472	.34598
20.K NITROG	138	.68000 -1	.49300	.16070	.62538 -1
21.CHLORIDE	128	1.5000	8.9000	5.0578	.90594
23.TOTAL P	137	.33000 -2	.12400 -1	.52431 -2	.16295 -2
25.CHLOROPH	138	.90000	7.8000	1.7993	.88338
26.POC	138	.24000 -1	.72600	.19207	.11152
28.SECCHI	54	3.5000	16.000	9.2722	2.9438

Table 4.4. Cruise three descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	138	2.7900	13.500	8.0004	3.0495
9.PH	138	7.9900	8.7400	8.2785	.15346
11.CONDUCTI	138	98.000	234.00	190.96	26.180
14.NH3	138	.10000 -2	.38000 -1	.23913 -2	.35503 -2
15.NO3	138	.16100	.76500	.27654	.55868 -1
16.ORTHO PO	138	.20000 -3	.14000 -2	.70652 -3	.18765 -3
17.SOL SIO2	138	.51000	2.6800	1.3854	.35510
18.K NITROG	138	.60000 -1	.32200	.12445	.33915 -1
19.CHLORIDE	138	1.3000	7.2000	5.1065	.95994
21.TOTAL P	138	.28000 -2	.73000 -2	.45406 -2	.87451 -3
23.CHLOROPH	138	.90000	4.7000	1.9565	.60145
24.POC	138	.11300	.60000	.22330	.68143 -1
26.SECCHI	73	2.5000	12.000	6.8425	2.0427

Table 4.5. Cruise four descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	138	11.900	22.000	18.819	1.7061
9.PH	138	7.7800	9.2200	8.1885	.14852
11.CONDUCTI	138	101.00	263.00	188.73	24.208
14.NH3	138	.10000 -2	.11000 -1	.31812 -2	.17561 -2
15.NO3	138	.13800	.32900	.23962	.30087 -1
16.ORTHO PO	136	.10000 -3	.17000 -2	.39338 -3	.25912 -3
17.SOL SIO2	138	0.	2.1300	1.0475	.34200
18.K NITROG	138	.87000 -1	.25700	.15324	.30401 -1
19.CHLORIDE	106	1.3000	7.0000	5.0481	.94760
21.TOTAL P	138	.23000 -2	.90000 -2	.41572 -2	.12776 -2
23.CHLOROPH	138	.30000	9.4000	1.2420	.81776
24.POC	138	.11000 -1	.34100	.20016	.53643 -1
26.SECCHI	93	1.5000	17.600	9.0935	2.3806

in excess of 4°C. Nearshore thermal warming had progressed to the stage where early thermal stratification had developed up to 10 km offshore. Figure 4.1 shows large nearshore areas during cruise three with surface temperatures in excess of 10°C.

Lake Huron was completely thermally stratified during cruise four (late July). Surface temperatures had reached a mean of 18.8°C (Table 4.5). The depth of the thermocline varied across the lake but ranged from 13 m in the southern end of the lake to 5 m in the deepest part of the lake near station 48. Figure 4.1 shows that there was a large range of surface temperatures across Lake Huron from less than 15°C to greater than 21°C.

Thermal stratification continued through cruise five (mid-September), although some cooling had occurred between cruises four and five. Table 4.6 shows that surface temperatures were lower in September (mean = 16.2°C) than July. Figure 4.1 shows that the highest surface temperatures were found in the southern and central parts of Lake Huron, while the lowest temperatures were nearshore in the north channel. The average depth of the thermocline was 23 m in September.

Cruise six was conducted during late October and early November. Although surface water temperatures had cooled considerably from the previous cruise in September, Lake Huron was still fully stratified. Figure 4.1 shows uniform surface temperatures with a mean of 8.2°C (Table 4.7). The thermocline at 85 m had deepened considerably from fall cooling and mixing since cruise five. Those parts of Lake Huron which have water depths in excess of 85 m could still be characterized as completely stratified, but the thermal gradient between the surface and bottom was only 4°C.

Table 4.6. Cruise five descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	138	11.400	22.600	16.229	2.6205
9.PH	138	7.7000	8.6600	8.2254	.16387
11.CONDUCTI	137	95.000	234.00	182.23	16.075
14.NH3	138	.10000 -2	.13000 -1	.15362 -2	.15291 -2
15.NO3	138	.17200	.29300	.23507	.20620 -1
16.ORTHO PO	138	.10000 -3	.17000 -2	.73116 -3	.24903 -3
17.SOL SIO2	138	.56000	2.1500	1.0209	.27873
18.K NITROG	138	.12100	.33400	.17641	.38985 -1
19.CHLORIDE	138	1.4000	7.3000	5.1355	.68122
21.TOTAL P	138	.29000 -2	.95000 -2	.43522 -2	.10250 -2
23.CHLOROPH	138	.80000	2.8000	1.4014	.34809
24.POC	138	.14500	.48400	.22257	.53869 -1
26.SECCHI	68	1.5000	11.000	6.2485	2.3193

Table 4.7. Cruise six descriptive statistics for 1-m samples.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
8.TEMPERAT	138	5.2100	11.600	8.2165	1.4167
9.PH	138	7.1500	8.5600	8.1822	.16022
11.CONDUCTI	137	99.000	267.00	198.82	19.363
14.NH3	138	.10000 -2	.10000 -1	.26812 -2	.17299 -2
15.NO3	138	.16300	.31200	.26510	.25112 -1
16.ORTHO PO	138	.20000 -3	.28000 -2	.58841 -3	.30401 -3
17.SOL SIO2	138	.76000	2.2100	1.2951	.27798
18.K NITROG	138	.10300	.50400	.17501	.53133 -1
19.CHLORIDE	138	1.3000	8.0000	5.2522	.75283
21.TOTAL P	138	.33000 -2	.11300 -1	.52486 -2	.15121 -2
23.CHLOROPH	138	.60000	4.7000	1.5348	.65698
24.POC	138	.11400	.59600	.21285	.88008 -1
26.SECCHI	69	1.0000	9.0000	4.2754	1.8875

Conductivity and Chloride Distribution

The distribution of the conservative tracers conductivity and chloride did not show a seasonal trend. These two variables should be unaffected by either temperature or the biota (Hutchinson 1957, Wetzel 1975). The areal distribution for conductivity and chloride was considered a result of two factors: (1) sources of high or low conductivity water, and (2) surface mixing of water masses. The second factor, surface mixing, is affected by the thermal cycle. For example, the thermal bar tends to act as a barrier to horizontal water mass exchange (Boyce 1974). But, Scavia and Bennett (1980) have shown that the thermal bar enhances vertical mixing. Figures 4.2 and 4.3 show the surface distribution of conductivity and chloride respectively for cruises one through six (cruise one chloride data are missing).

Figures 4.2 and 4.3 show a high degree of agreement in the areal distribution of conductivity and chloride, which was confirmed by correlation analyses (see Chapter Seven). A previous study (Schelske et al. 1980, Moll et al. 1980) attributed high chloride levels in southern Lake Huron to inputs from Saginaw Bay. Likewise, in the Straits of Mackinac, high chloride water was a result of inflowing Lake Michigan water (Moll et al. 1976). Low chloride water in the northeastern Straits region was attributed to inflowing Lake Superior water.

The areal distribution of conductivity during cruise one shows the effect of the two high conductivity and one low conductivity sources. High chloride water was observed on the southern edge of Saginaw Bay along the north shore of Michigan's "thumb" and in the Straits of Mackinaw. Low conductivity water dominated the western end of the north channel, the entire northwestern end of open Lake Huron, and parts of Georgian Bay (Fig. 4.2). Several small regions

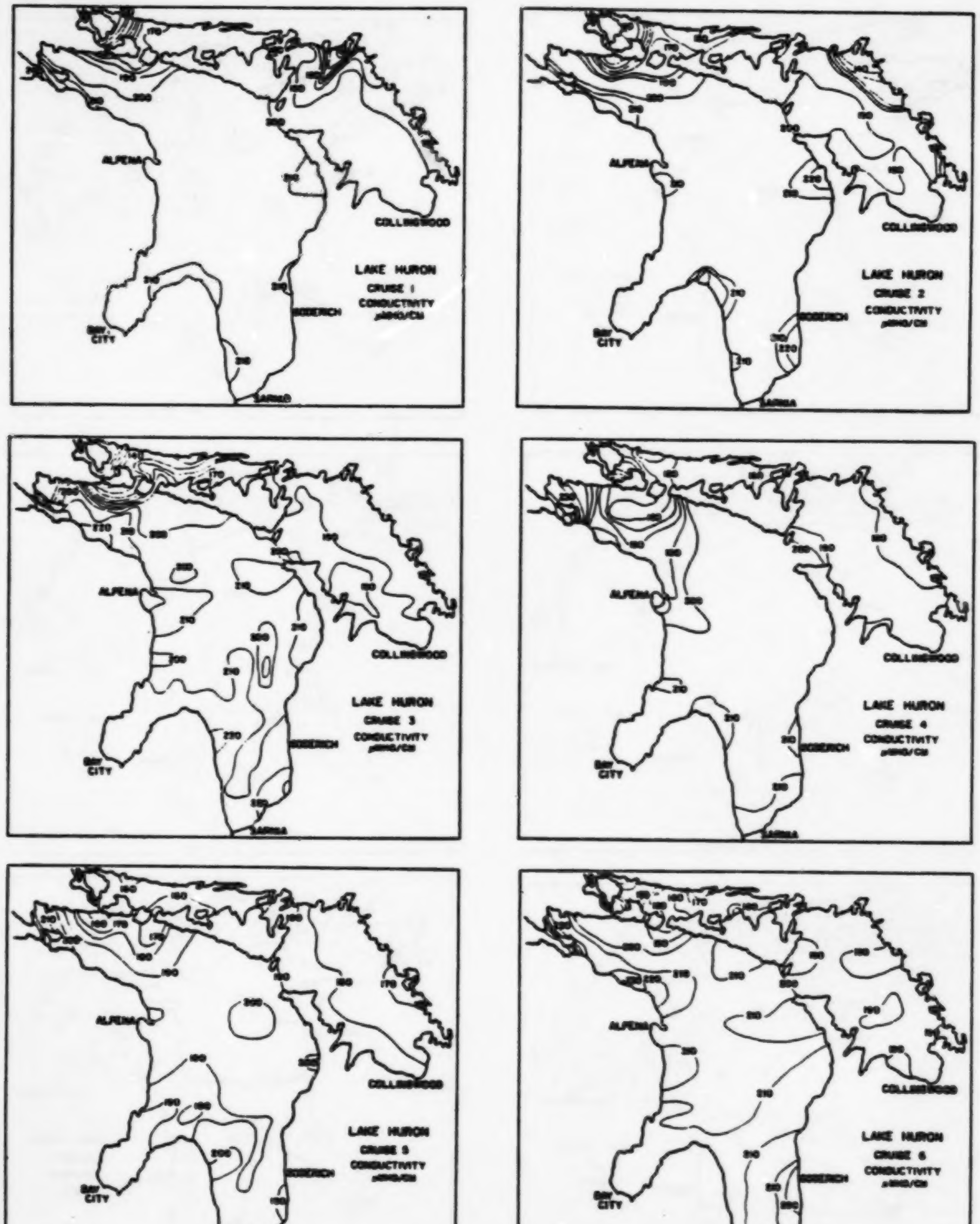

LAKE HURON
CRUISE 1
CONDUCTIVITY
µMHO/CM
LAKE HURON
CRUISE 2
CONDUCTIVITY
µMHO/CM
LAKE HURON
CRUISE 3
CONDUCTIVITY
µMHO/CM
LAKE HURON
CRUISE 4
CONDUCTIVITY
µMHO/CM
LAKE HURON
CRUISE 5
CONDUCTIVITY
µMHO/CM
LAKE HURON
CRUISE 6
CONDUCTIVITY
µMHO/CM
ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA

Figure 4.2 One-meter conductivity distribution during 1980.

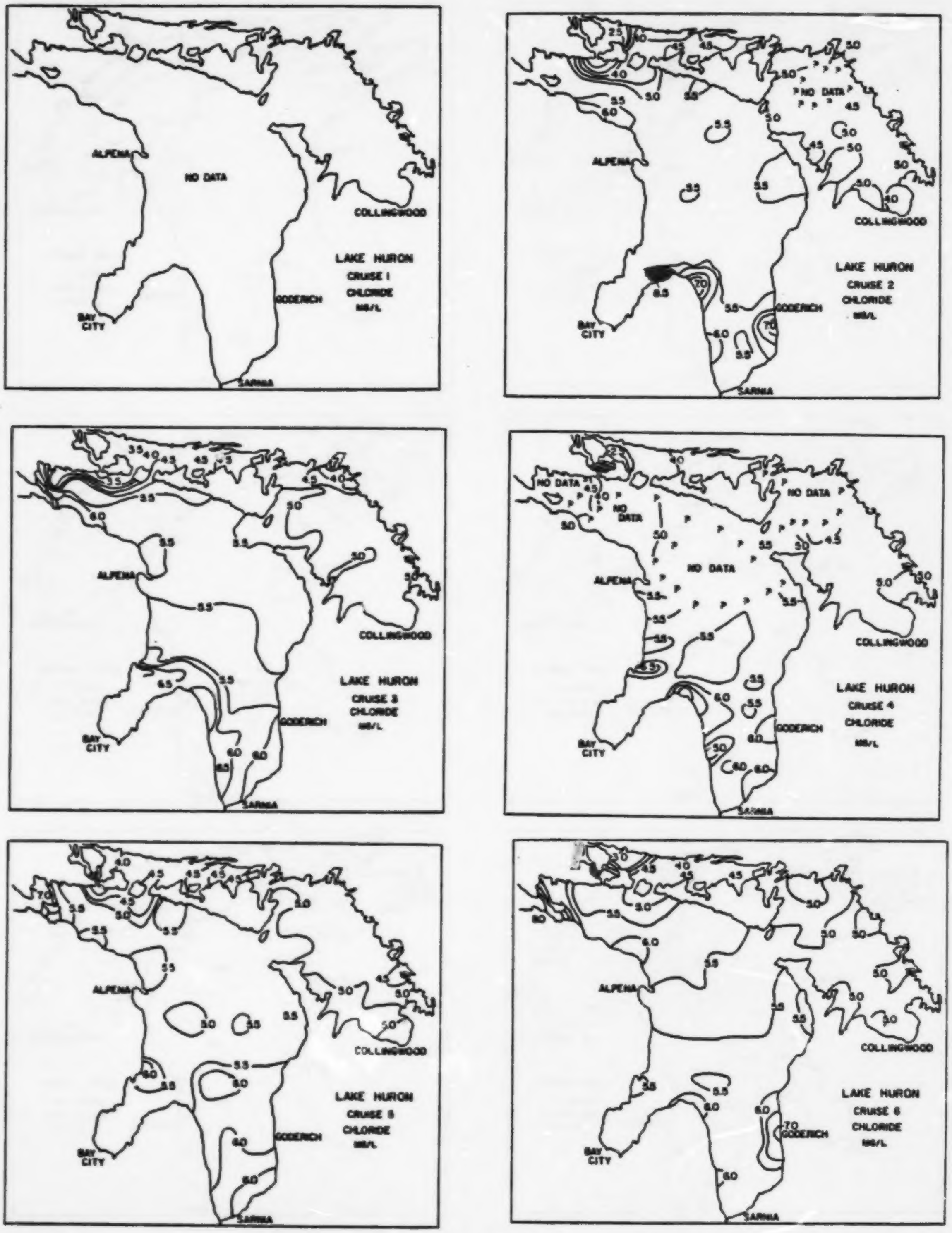

ALPENA
NO DATA
COLLINGWOOD
LAKE HURON
CRUISE 1
CHLORIDE
MG/L
GODERICH
BAY CITY
SARNIA
LAKE HURON
CRUISE 2
CHLORIDE
MG/L
LAKE HURON
CRUISE 3
CHLORIDE
MG/L
LAKE HURON
CRUISE 4
CHLORIDE
MG/L
LAKE HURON
CRUISE 5
CHLORIDE
MG/L
LAKE HURON
CRUISE 6
CHLORIDE
MG/L

Figure 4.3 One-meter chloride distribution during 1980.

of high conductivity water were observed in the nearshore regions; these high conductivity regions were interpreted as outflow of small rivers which often carry high chloride loads in the early spring (Schelske et al. 1980). The low conductivity area of Georgian Bay was attributed to a low chloride river discharge.

During cruise two the same conductivity pattern was observed as cruise one, except that nearshore conductivities were higher, raising the lake-wide, surface conductivity mean from cruise one (Fig. 4.2, Tables 4.2 and 4.3). The higher nearshore conductivities of cruise two were attributed to high river discharges during the spring thaw. The areal distributions of conductivity and chloride during cruise two were very similar (Figs. 4.2 and 4.3).

Cruises three through six produced very similar conductivity and chloride distributions (Figs. 4.2 and 4.3). Conductivity and chloride values in southern and open Lake Huron were uniform at approximately 205-210 μmho/cm and 5.5 to 6.0 mg/L, respectively. Regions of high conductivity and chloride water in Lake Huron's southern basin were confined to the edge of Saginaw Bay along Michigan's "thumb." This area appears to be a location where Saginaw Bay water typically mixes into open Lake Huron (Schelske et al. 1980). Two regions of low chloride and conductivity water were observed during cruises three to six; the North Channel and adjacent open lake where Lake Superior water mixes into Lake Huron, and the north edge of Georgian Bay. The distribution of low chloride and conductivity water in the North Channel and adjacent region changed somewhat from cruise to cruise and was attributed to wind-induced mixing. For example, the cruise four areal distribution shows an almost north-south gradient between the low and average chloride waters while cruise six showed an east-west gradient.

Despite changes in distribution, conductivity and chloride concentrations changed very little from April through November.

Seasonal Nutrient Cycles

Soluble Silica — Research over the past twenty years has shown soluble silica undergoes a consistent annual cycle in the Great Lakes (Schelske and Stoermer 1971, Kilham 1971, Rousar 1973). This annual silica cycle has been attributed to increased phosphorus levels which promote diatom growth and hence silica uptake (Schelske and Stoermer 1971). The annual soluble silica cycle in surface waters begins with high soluble levels in the spring, goes through a severe depletion in the summer, and slow replenishment throughout the fall and winter (Rousar 1973, Rousar and Beeton 1973).

This annual pattern of soluble silica concentrations was observed in Lake Huron, but to a much lesser extent than in Lake Michigan (Schelske and Roth 1973). Lake Huron water is composed primarily of a mixture of Lake Michigan and Lake Superior outflows. Lake Superior waters have relatively high and consistent silica levels, while Lake Michigan waters readily display an annual cycle as described above (Rockwell *et al*. 1980). Because the Lake Superior inflow vastly exceeds the Lake Michigan inflow, soluble silica cycles in northwestern Lake Huron showed very little seasonal change (Fig. 4.4).

Soluble silica concentrations in central Lake Huron, southern Lake Huron, and Georgian Bay somewhat followed the annual cycle described above in conjunction with the thermal cycle. Figure 4.4 shows high surface silica levels for cruise one with a mean of 1.5 mg/L SiO_2 (Table 4.2). The areal distribution of silica was the same throughout all cruises: low soluble silica levels near

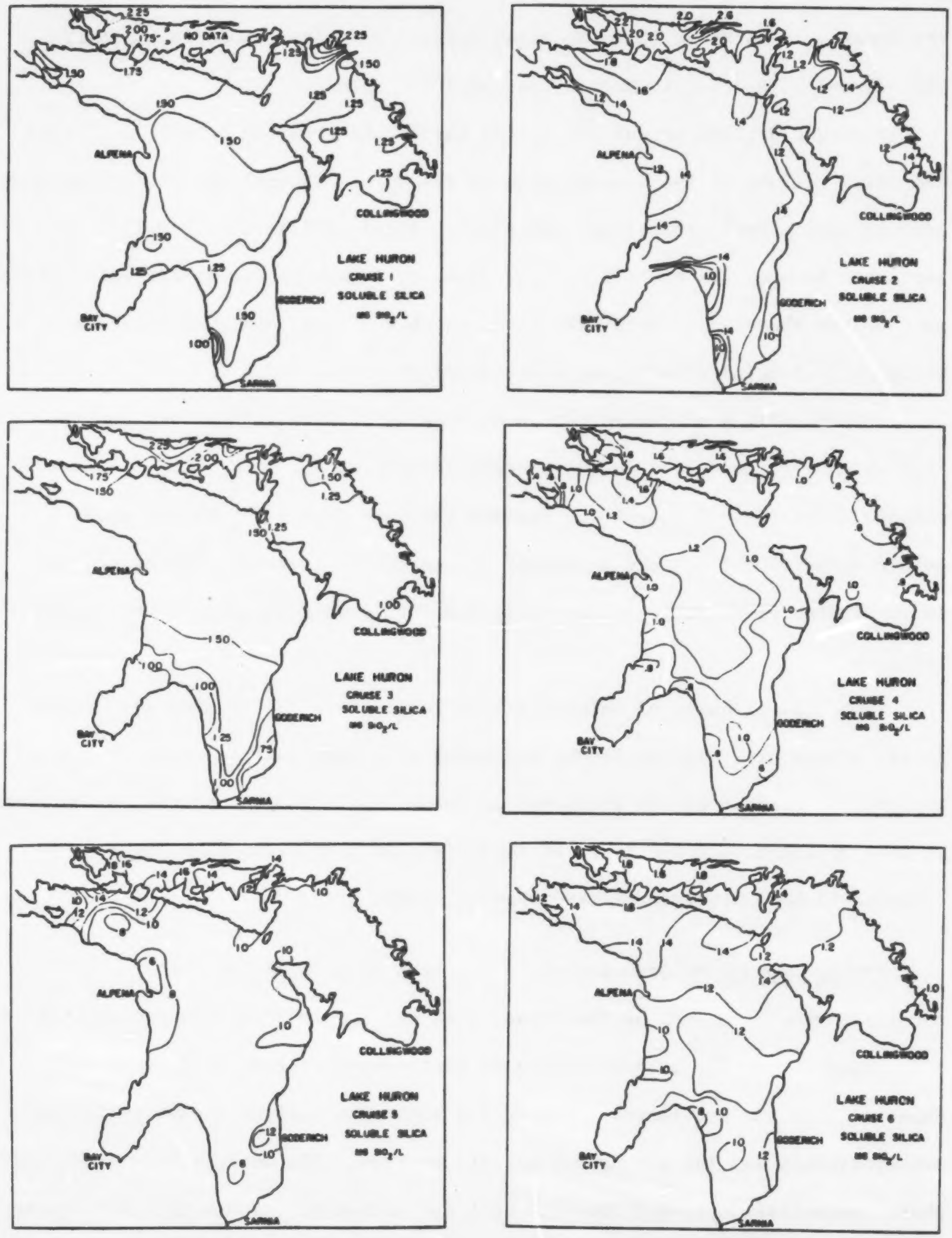

ALPENA
BAY CITY
SARNIA
GODERICH
COLLINGWOOD
NO DATA
LAKE HURON CRUISE 1 SOLUBLE SILICA mg SiO2/L
LAKE HURON CRUISE 2 SOLUBLE SILICA mg SiO2/L
LAKE HURON CRUISE 3 SOLUBLE SILICA mg SiO2/L
LAKE HURON CRUISE 4 SOLUBLE SILICA mg SiO2/L
LAKE HURON CRUISE 5 SOLUBLE SILICA mg SiO2/L
LAKE HURON CRUISE 6 SOLUBLE SILICA mg SiO2/L

Figure 4.4 One-meter soluble silica distribution during 1980.

the Straits of Mackinaw (Lake Michigan water), and high levels in the North Channel and adjacent Lake Huron (Lake Superior water).

A slight decline in surface silica levels was observed between the first and third cruises as the mean dropped to 1.4 mg/L. Thermal bar conditions were present during both cruises two and three. Algal utilization of silica was indicated between the thermal bar and shore by a band of low silica water along most of the shoreline. Open Lake Huron soluble silica levels declined only very slightly (0.1 mg/L) from spring concentrations.

Soluble silica concentrations continued to decline through cruises four and five which were conducted during thermal stratification. The surface means of soluble silica were 1.0 mg/L for cruises four and five. Figure 4.4 shows a continuation of the pattern of lowest silica levels nearshore during cruise four. Cruise five, on the other hand, had fairly uniform areal silica concentrations.

Some replenishment of soluble silica levels from fall mixing was evident during cruise six. Silica levels increased to a mean surface value of 1.3 mg/L. In summary, soluble silica displayed an annual cycle similar to the one observed in Lake Michigan, but the level of depletion was much lower than has been observed in Lake Michigan (Rockwell et al. 1980).

Orthophosphate -- Orthophosphate has been considered the limiting nutrient for algal growth in most of the Great Lakes (Beeton 1969). A consequence of the high algal demand for orthophosphate is that concentrations tend to be very low, especially in the epilimnion. Figure 4.5 shows the surface concentration of orthophosphate was low throughout all six cruises. The mean surface orthophosphate concentration ranged from 0.8 µg/L for cruise one to 0.4 µg/L for cruise four.

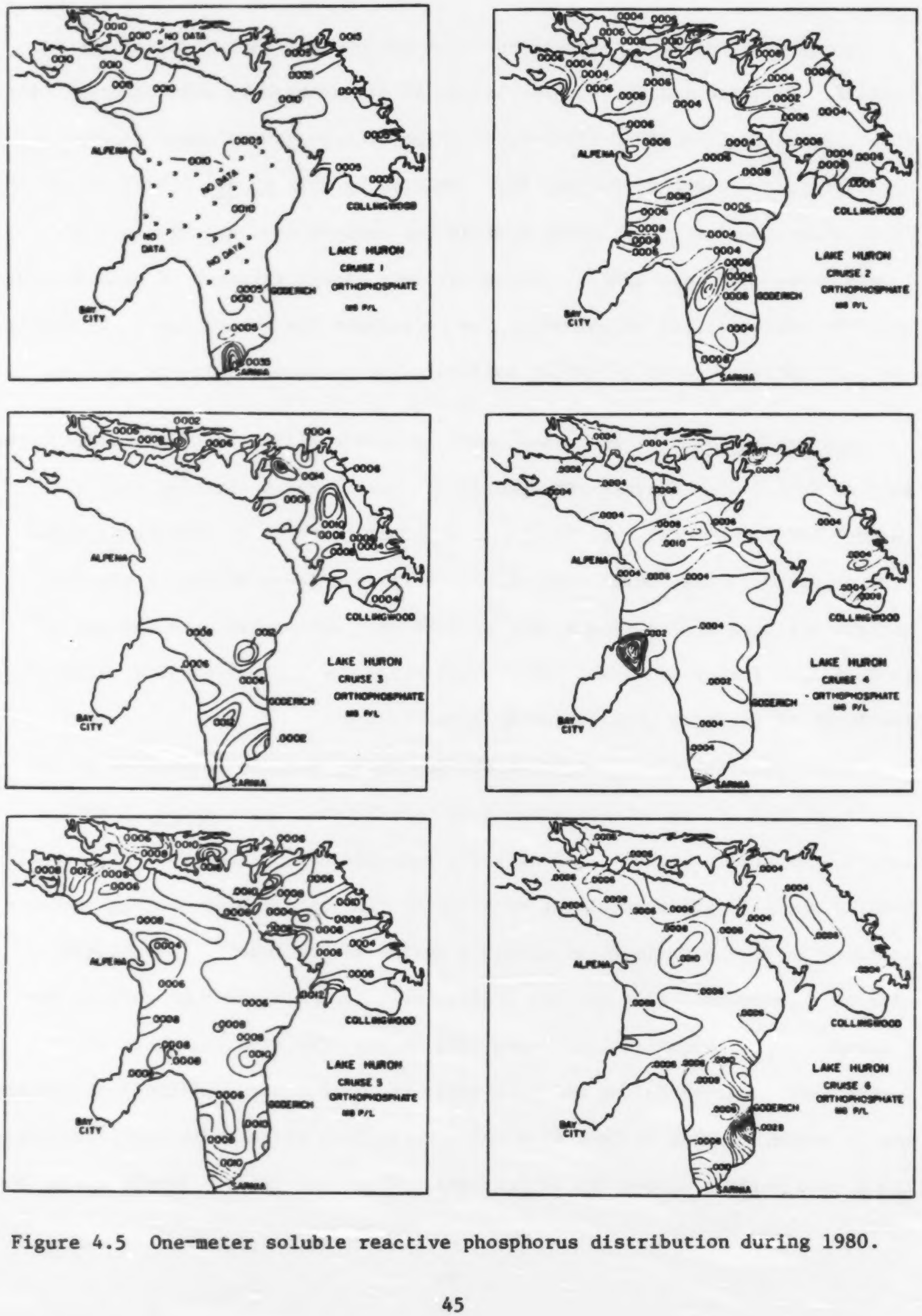
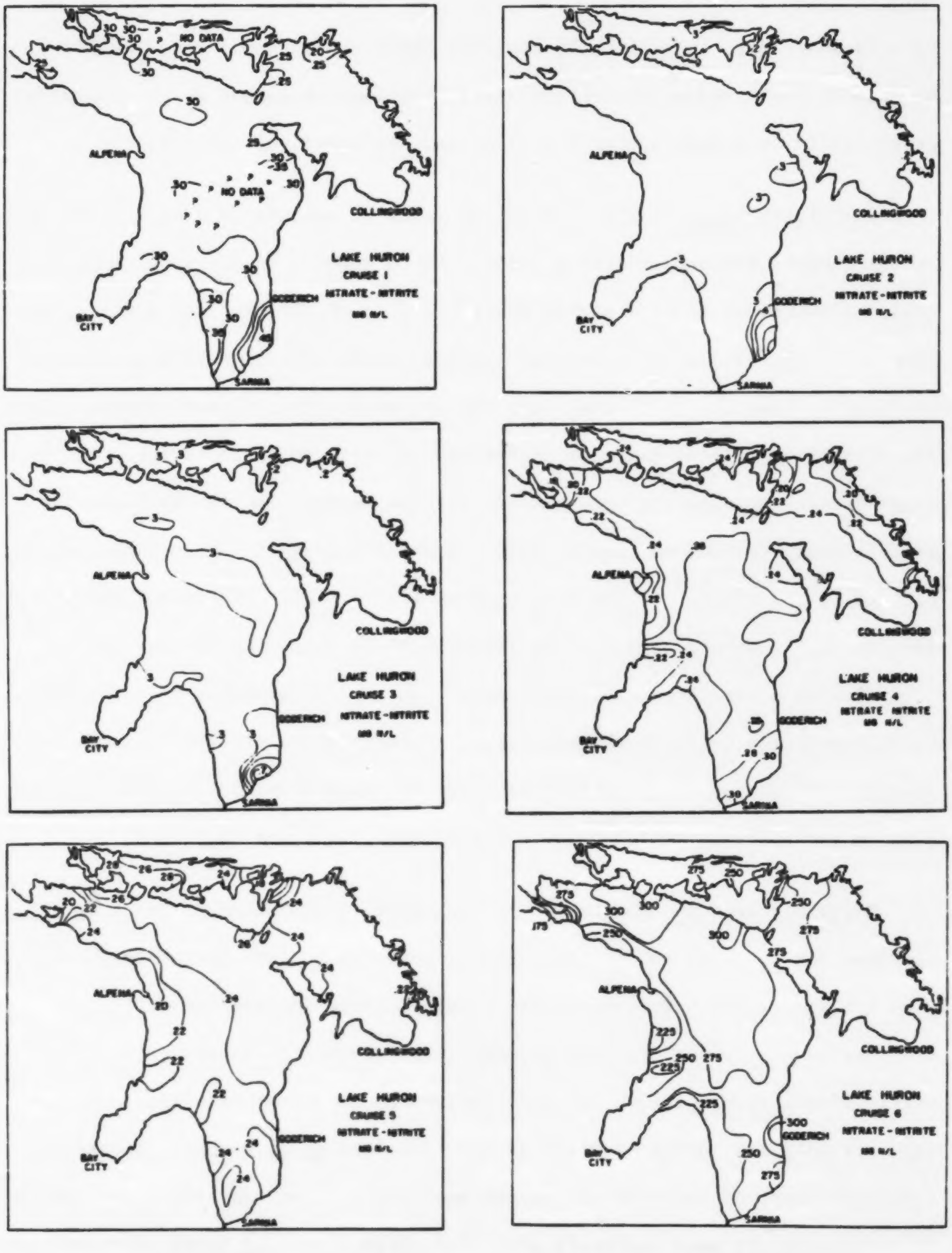

LAKE HURON
CRUISE 1
ORTHOPHOSPHATE
MG P/L
NO DATA
ALPENA
BAY CITY
GODERICH
SARNIA
COLLINGWOOD
LAKE HURON
CRUISE 2
ORTHOPHOSPHATE
MG P/L
LAKE HURON
CRUISE 3
ORTHOPHOSPHATE
MG P/L
LAKE HURON
CRUISE 4
ORTHOPHOSPHATE
MG P/L
LAKE HURON
CRUISE 5
ORTHOPHOSPHATE
MG P/L
LAKE HURON
CRUISE 6
ORTHOPHOSPHATE
MG P/L

Figure 4.5 One-meter soluble reactive phosphorus distribution during 1980.

Areal patterns of orthophosphate were not evident during any of the cruises. In a few instances, high levels of orthophosphate were observed nearshore, probably from river discharges. High orthophosphate water was not observed in the mouth of Saginaw Bay. Studies by Moll *et al.* (1980) showed that large algal populations in inner Saginaw Bay reduced most soluble nutrient levels below open lake ambient concentrations. Areal patterns of orthophosphate could be characterized as uniformly low throughout the entire lake. Similarly, seasonal patterns could be called uniformly low throughout all six cruises.

Nitrate-Nitrogen — In predominantly phosphorus-limited oligotrophic lakes such as Lake Huron, nitrate-nitrogen is not considered a limiting nutrient (Wetzel 1975). Nonetheless, areal and seasonal patterns of nitrate-nitrogen were observed in Lake Huron (Fig. 4.6). Surface concentrations of soluble nitrate-nitrogen ranged from a mean of 0.28 mg/L for cruises one through three to 0.24 mg/L for cruise four. This small range was indicative of a relatively low level of nitrogen utilization by phytoplankton.

Areal patterns of nitrate distribution were primarily determined by the inflow of high or low nitrate water into Lake Huron. Davis *et al.* (1980) measured extremely high nitrate-nitrogen concentrations along the Province of Ontario shore during thermal bar conditions. They attributed the high concentrations to high nitrate river outflows during spring runoff. The highest nitrate concentrations of all six cruises were found in the same region, the Ontario shore of southern Lake Huron (Fig. 4.6). The high nearshore nitrate levels were observed during and just prior to thermal bar conditions of cruises one to three. During cruises five and six, surface nitrate-nitrogen concentrations were uniform across the entire lake. Thus, the nitrate levels along the



LAKE HURON
CRUISE 1
NITRATE - NITRITE
NO DATA
ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA
LAKE HURON
CRUISE 2
NITRATE - NITRITE
LAKE HURON
CRUISE 3
NITRATE - NITRITE
LAKE HURON
CRUISE 4
NITRATE NITRITE
LAKE HURON
CRUISE 5
NITRATE - NITRITE
LAKE HURON
CRUISE 6
NITRATE - NITRITE

Figure 4.6 One-meter nitrate plus nitrite distribution during 1980.

Ontario shore were only slightly elevated above ambient open lake levels. Nitrate-nitrogen annual cycles and areal distribution appear to be controlled primarily by exogenous nitrogen sources and not algal utilization.

Ammonia-Nitrogen — The nutrient dynamics of ammonia tend to fall between orthophosphate and nitrate (Fogg 1975). While ammonia is not considered a limiting nutrient, it is a highly available form of nitrogen for algal uptake (Eppley et al. 1969). As a result, ammonia concentrations remain at constant low levels. Ammonia originates from one of two sources, either aquatic animal excretion (zooplankton and fish excretion) or local domestic sewage outfalls. Large sewage outfalls are not abundant in Lake Huron. The annual range in ammonia concentration was small, with a mean of 3.1 µg N/L for cruises one and four to 1.5 µg N/L for cruise five (Tables 4.2 to 4.7). Figure 4.7 shows that ammonia levels were consistent and low across the open lake for all cruises. Occasionally a nearshore area would have higher ammonia levels than the open lake, especially in southern Lake Huron. Ammonia areal distribution was analogous to orthophosphate distribution; concentrations were consistently low and uniform and probably kept at low levels by algal utilization.

Total Nitrogen and Phosphorus -- The areal distribution of total (Kjeldahl) nitrogen and total phosphorus for the six research cruises are shown in Figures 4.8 and 4.9, respectively. The seasonal cycle and areal distribution of these two variables are tied closely to phytoplankton biomass and productivity (Paerl et al. 1975). Because Lake Huron is primarily oligotrophic, it supports only low levels of algal growth (Schelske et al. 1980). Therefore, throughout most of the year and across much of the open lake total nitrogen and phosphorus levels were uniformly low. But, high levels of total nitrogen and

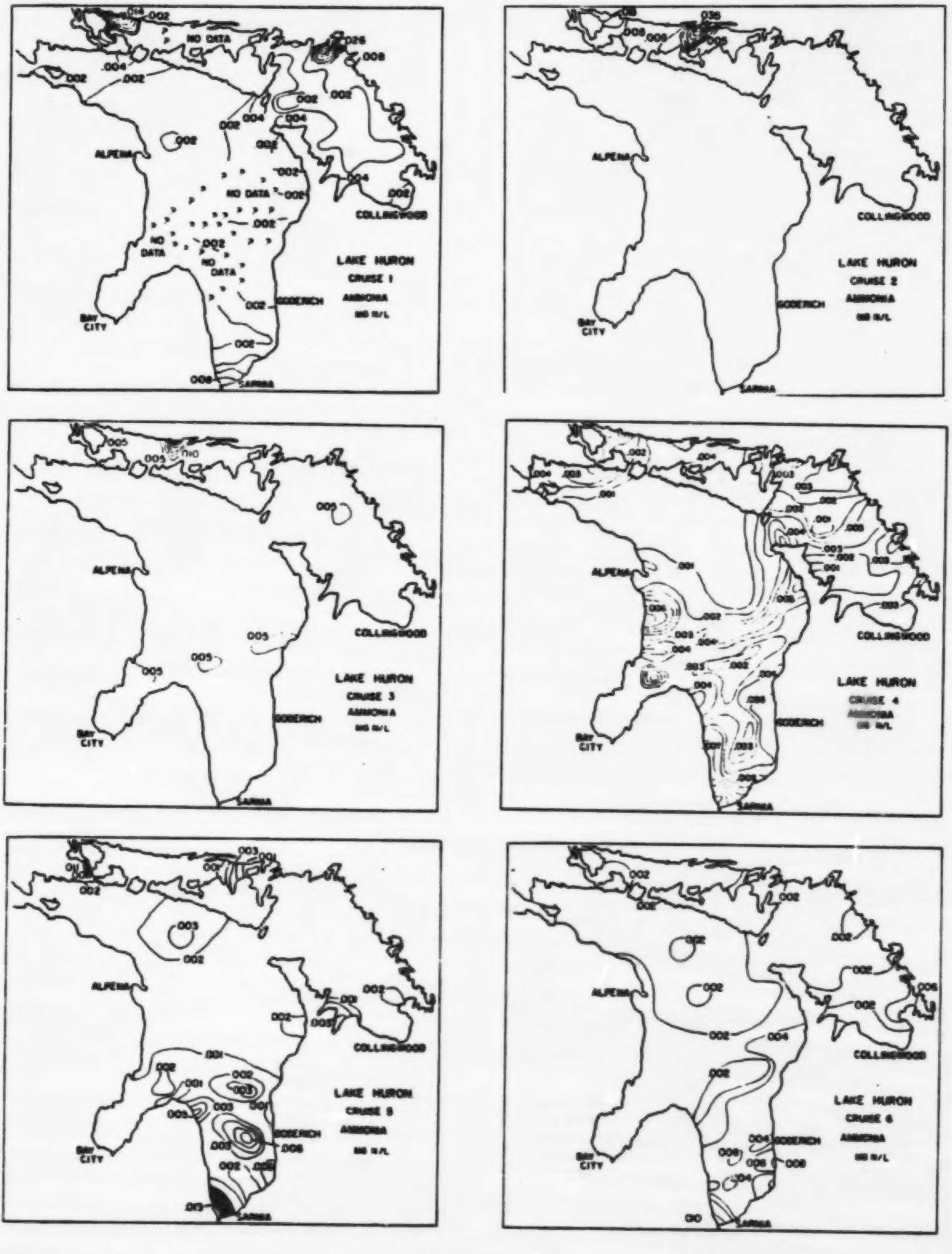

LAKE HURON
CRUISE 1
AMMONIA
MG N/L
NO DATA
ALPENA
BAY CITY
GODERICH
COLLINGWOOD
SARNIA
LAKE HURON
CRUISE 2
AMMONIA
MG N/L
LAKE HURON
CRUISE 3
AMMONIA
MG N/L
LAKE HURON
CRUISE 4
AMMONIA
MG N/L
LAKE HURON
CRUISE 5
AMMONIA
MG N/L
LAKE HURON
CRUISE 6
AMMONIA
MG N/L

Figure 4.7 One-meter ammonium ion distribution during 1980.

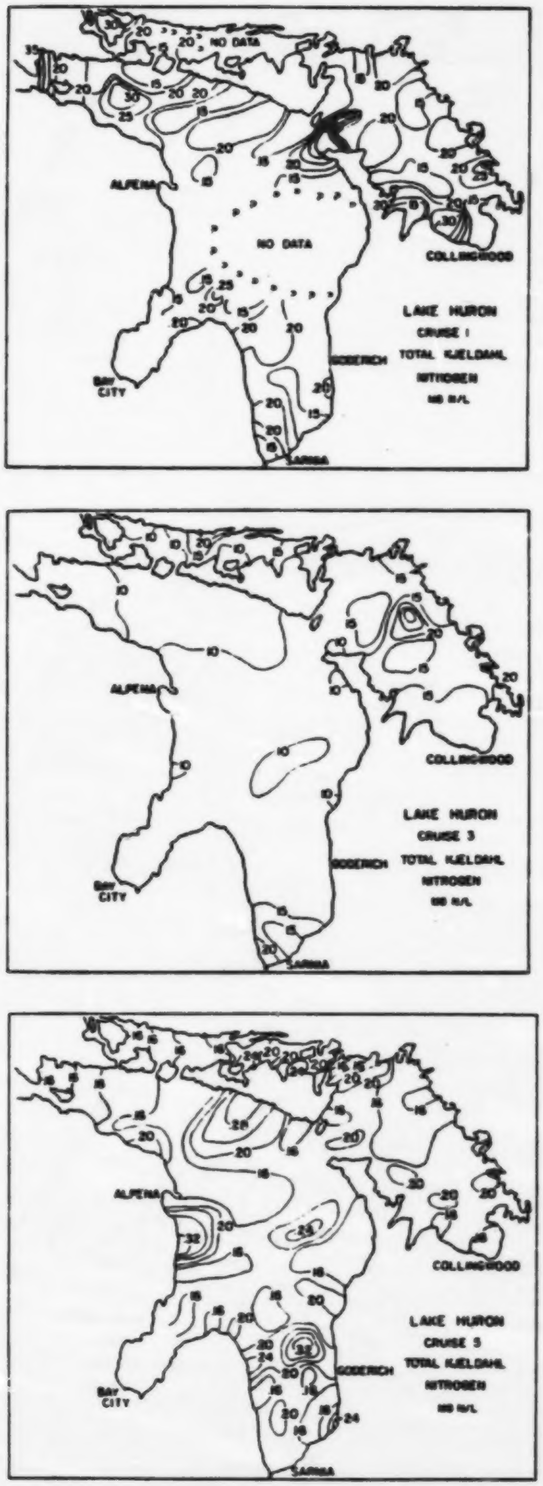

LAKE HURON
CRUISE 1
TOTAL KJELDAHL NITROGEN
MG N/L
NO DATA
ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA
LAKE HURON
CRUISE 2
TOTAL KJELDAHL NITROGEN
MG N/L
LAKE HURON
CRUISE 3
TOTAL KJELDAHL NITROGEN
MG N/L
LAKE HURON
CRUISE 4
TOTAL KJELDAHL NITROGEN
MG N/L
LAKE HURON
CRUISE 5
TOTAL KJELDAHL NITROGEN
MG N/L
LAKE HURON
CRUISE 6
TOTAL KJELDAHL NITROGEN
MG N/L

Figure 4.8 One-meter Kjeldahl nitrogen distribution during 1980.

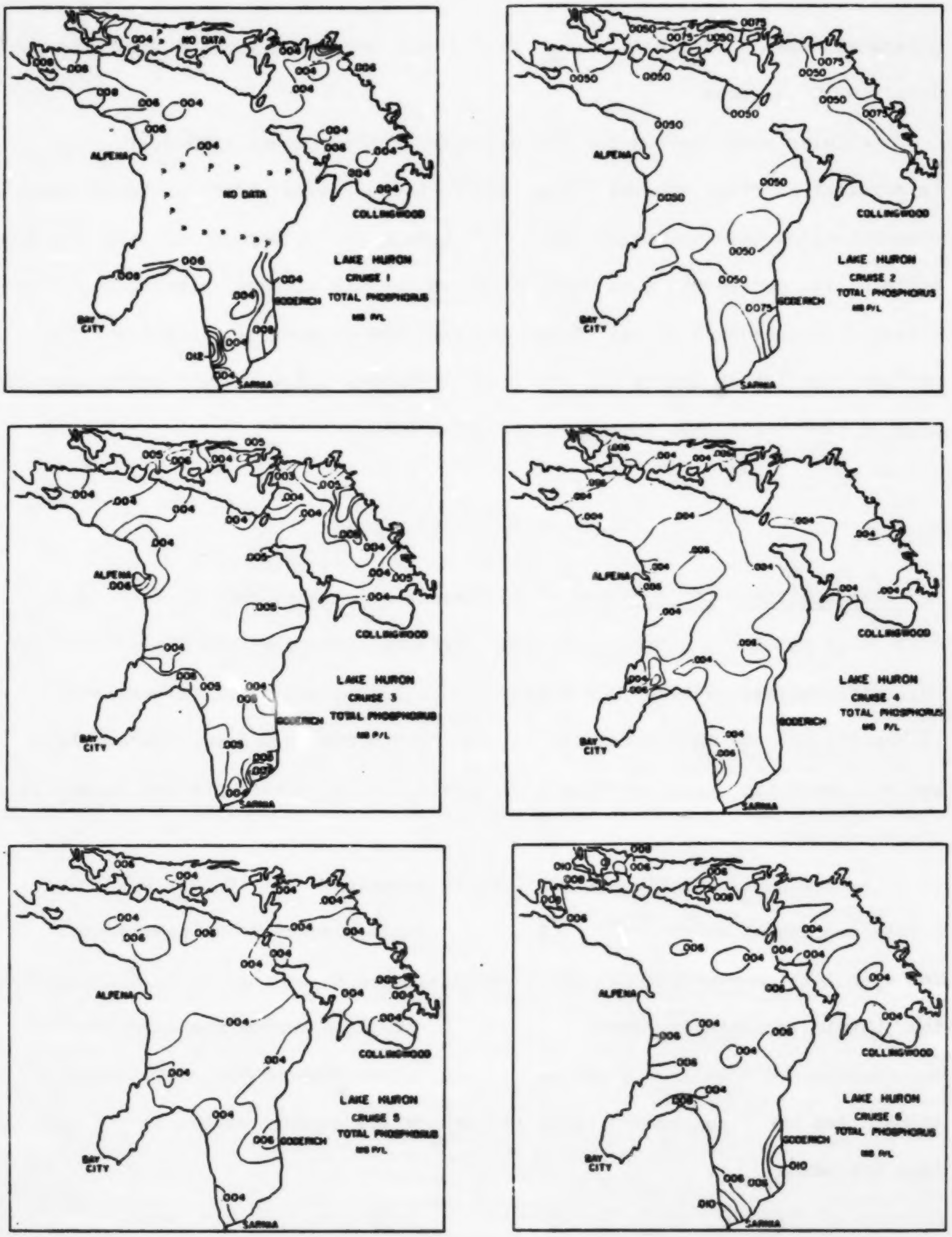

LAKE HURON
CRUISE 1
TOTAL PHOSPHORUS
MG P/L
NO DATA
ALPENA
BAY CITY
COLLINGWOOD
GODERICH
SARNIA
LAKE HURON
CRUISE 2
TOTAL PHOSPHORUS
MG P/L
LAKE HURON
CRUISE 3
TOTAL PHOSPHORUS
MG P/L
LAKE HURON
CRUISE 4
TOTAL PHOSPHORUS
MG P/L
LAKE HURON
CRUISE 5
TOTAL PHOSPHORUS
MG P/L
LAKE HURON
CRUISE 6
TOTAL PHOSPHORUS
MG P/L

Figure 4.9 One-meter total phosphorus distribution during 1980.

phosphorus were occasionally found in the nearshore zone where soluble nutrient levels were elevated.

Cellular algal phosphorus and nitrogen levels are determined, in part, by external nutrient sources (Fogg 1975). As mentioned above, orthophosphate concentrations were uniformly low across Lake Huron throughout all six cruises. Soluble nitrogen levels were uniform across the six seasons, but occasionally elevated in nearshore areas. Total nitrogen and phosphorus reflect the same pattern; consistent across all six cruises (Tables 4.2-4.7), and uniform across most of the lake except in some nearshore areas.

Seasonal Biological Cycles

Particulate Organic Carbon -- In oligotrophic lakes such as Lake Huron, sources of particulate organic carbon originate primarily from biological productivity (Wetzel 1975). Thus algal cells and zooplankton contribute most, if not all, of the particulate organic matter to the open lake. Particulate matter from river runoff creates high levels of particulate organic carbon in the nearshore zone.

The areal distribution of particulate organic carbon (Figure 4.10) was fairly consistent in the open lake and elevated concentrations near shore. The open lake concentrations, which are dominated by phytoplankton and zooplankton, showed some annual pattern; highest particulate carbon concentrations were observed in the late spring and early summer, the time of the spring algal bloom. But the total annual range in particulate organic carbon in the open lake was small.

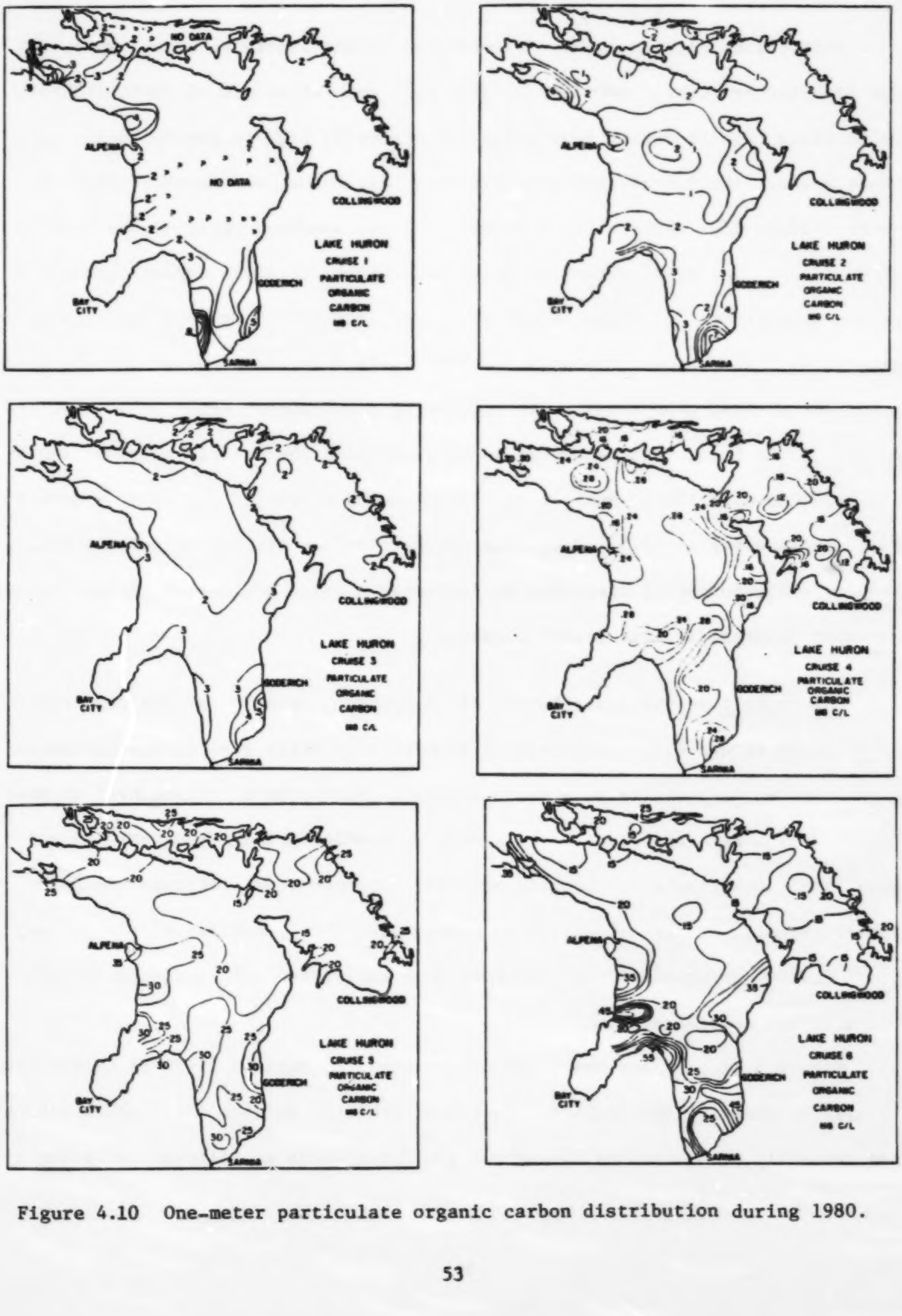

LAKE HURON CRUISE 1 PARTICULATE ORGANIC CARBON MG C/L
NO DATA
ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA
LAKE HURON CRUISE 2 PARTICULATE ORGANIC CARBON MG C/L
LAKE HURON CRUISE 3 PARTICULATE ORGANIC CARBON MG C/L
LAKE HURON CRUISE 4 PARTICULATE ORGANIC CARBON MG C/L
LAKE HURON CRUISE 5 PARTICULATE ORGANIC CARBON MG C/L
LAKE HURON CRUISE 6 PARTICULATE ORGANIC CARBON MG C/L

Figure 4.10 One-meter particulate organic carbon distribution during 1980.

Particulate organic carbon distribution in the nearshore areas apparently was affected by river runoff and locally high concentrations of phytoplankton. Particulate organic carbon levels were consistently high in the following nearshore areas: the Ontario shore of southern Lake Huron, the southern edge of outer Saginaw Bay, eastern Georgian Bay, and the southern shore of the Straits of Mackinaw. The areal extent of these elevated particulate organic carbon regions suggested that river runoff alone was unlikely to produce the elevated concentrations. Rather, the high nutrient loads from river runoff were probably stimulating algal productivity and increasing particulate carbon levels. Davis _et_ _al_. (1980) found this mechanism to operate along the Ontario shore of southern Lake Huron in 1974. Moll _et_ _al_. (1980) found a similar series of events in outer Saginaw Bay in 1975. Comparing the particulate organic carbon distribution to the chlorophyll distribution indicates a large portion of organic carbon contains chlorophyll (i.e., phytoplankton).

Chlorophyll — The distribution of chlorophyll biomass for the six cruises is shown in Figure 4.11. Chlorophyll biomass is closely tied to phytoplankton concentration, especially in surface samples. Furthermore, chlorophyll biomass has been used as a term in several models to predict primary productivity and as a response variable to changing nutrient concentrations (Bierman and Dolan 1981). Because of the relationships among chlorophyll, nutrients, and primary productivity, chlorophyll distributions have been thoroughly analyzed on both temporal and spatial scales.

Figure 4.11 presents the areal distribution of surface (1-20 m) chlorophyll levels for the six 1980 cruises. An annual cycle of surface chlorophyll values has typically been observed throughout the Great Lakes as follows: a spring

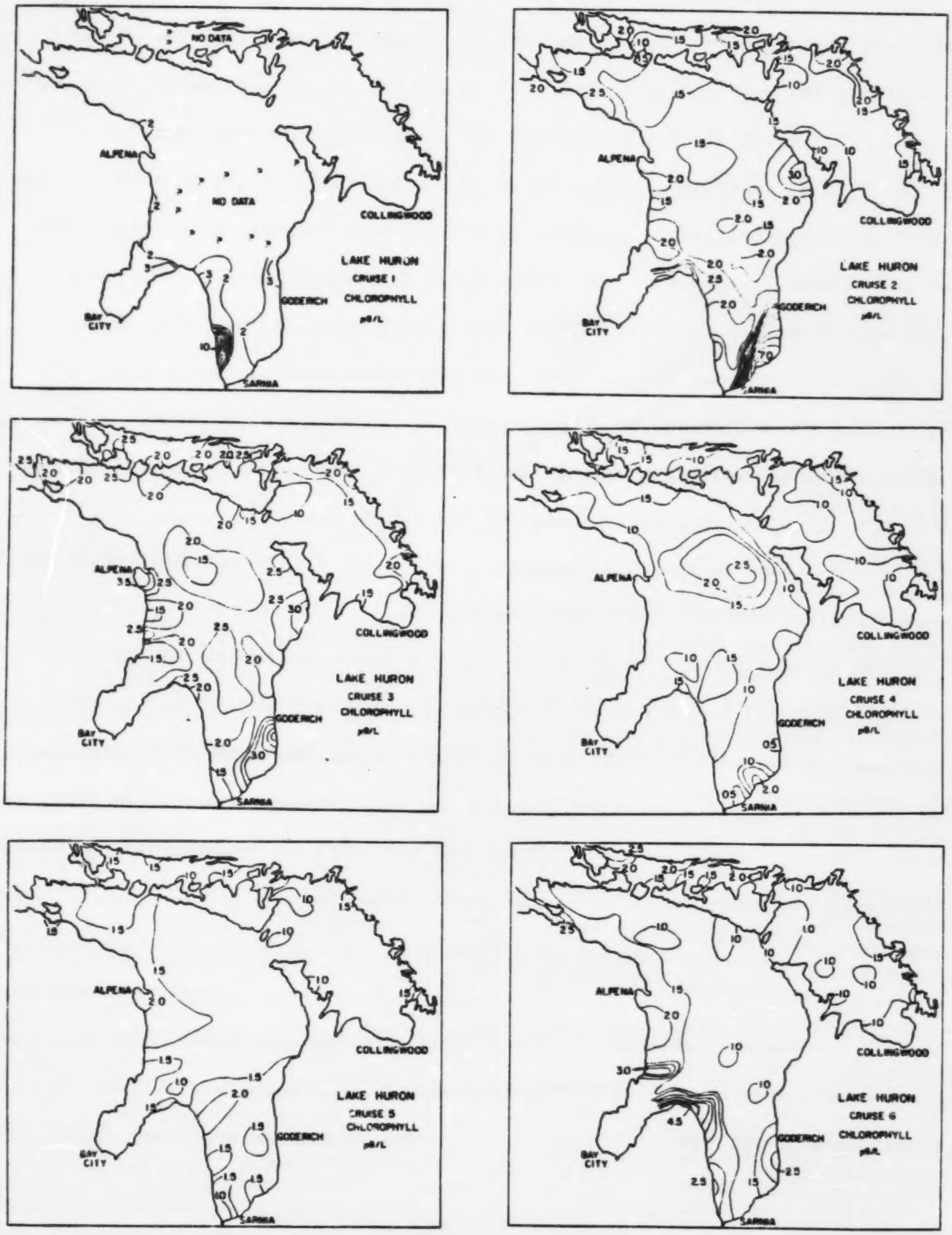

LAKE HURON
CRUISE 1
CHLOROPHYLL
µg/L
NO DATA
ALPENA
BAY CITY
SARNIA
GODERICH
COLLINGWOOD
LAKE HURON
CRUISE 2
CHLOROPHYLL
µg/L
LAKE HURON
CRUISE 3
CHLOROPHYLL
µg/L
LAKE HURON
CRUISE 4
CHLOROPHYLL
µg/L
LAKE HURON
CRUISE 5
CHLOROPHYLL
µg/L
LAKE HURON
CRUISE 6
CHLOROPHYLL
µg/L

Figure 4.11 One-meter chlorophyll distribution during 1980.

bloom of phytoplankton follows the annual minimum values during the winter; relatively low surface chlorophyll levels are typical of mid-summer, followed by a small fall algal bloom (Glooschenko and Moore 1973, Fee 1976, Munawar and Burns 1976, Vollenweider et al. 1974). The relatively low and invariant surface chlorophyll concentrations found in Lake Huron were indicative of oligotrophic lakes. Tables 4.2-4.7 show the mean surface chlorophyll values ranged from 1.24 μg/L during cruise four to 2.00 μg/L during cruise three. The annual pattern of chlorophyll in Lake Huron was consistent with the cycle described above, but the difference between spring bloom conditions and summer minimum was only 0.76 μg/L. The hypothesis presented by Moll and Stoermer (1982) indicates that the difference between the size of the spring bloom and annual minimum is just as important as the total biomass. Lake Huron's uniform annual chlorophyll levels further suggest oligotrophic conditions.

The areal distribution of chlorophyll is often used as an indication of areas of high algal growth due to nutrient loading (Holland and Beeton 1972, Robertson et al. 1971). Considered in this fashion, the chlorophyll distributions shown in Figure 4.11 again reflect the oligotrophic character of Lake Huron. During cruises one, two, three, and six, elevated chlorophyll concentrations were observed along the Ontario shore of southern Lake Huron. Other nearshore areas which exhibited elevated chlorophyll levels were: southern Saginaw Bay along Michigan's "thumb," extreme southern Lake Huron, eastern Georgian Bay, and the Straits of Mackinaw. During cruises one, two, and four, there were one or two stations with high chlorophyll levels (>7.0 μg/L). But, with few exceptions, chlorophyll concentrations in the nearshore regions mentioned above rarely exceeded lake-wide means by 3.0 μg/L.

One nearshore area of Lake Huron that deserved particular attention was the tip of Michigan's "thumb." In 1974 and 1975, this region was characterized by very high chlorophyll levels as a consequence of eutrophication in Saginaw Bay (Moll *et al*. 1980). Since that study, remedial measures have been used in an attempt to control Saginaw Bay pollution. The results shown in Figure 4.11 show very little increase in chlorophyll levels in this region above the adjacent open lake conditions.

Secchi Disc -- Water transparency as measured by the Secchi disc technique cannot be plotted for the 1980 study. Large blocks of the Secchi disc readings are missing because readings could not be made at night when the ships were operating 24 hours a day. Nonetheless, the statistics given in Tables 4.2-4.7 allow some comparison between 1980 Secchic depths and previous studies.

Secchi disc transparency typically follows the annual cycle of chlorophyll concentrations (Ladewski and Stoermer 1973). This close correspondence between chlorophyll and Secchi depth readings has led many researchers to suggest Secchi readings can determine trophic status, chlorophyll concentrations, nutrient concentrations, etc. (Carlson 1977). Although Secchi depths can indicate water clarity with high reproducibility, they cannot reliably estimate trophic status, chlorophyll biomass, etc. In Lake Huron, Secchi depths ranged from 1.0 to 16.0 meters (Tables 4.2-4.7) during 1980. Smallest Secchi depth readings were found during the third cruise (June), which occurred during thermal bar/spring bloom conditions. Largest Secchi depths were observed in the open lake during the fourth (July) cruise. It should be noted that the pattern of missing data has a large influence on the Secchi results. Many missing observations from the middle of Lake Huron would bias the mean depth toward smaller depths measured in the nearshore and vice versa. As a consequence of the possible bias created by the missing observations, the Secchi depth data provide few inferences beyond the relationship with chlorophyll biomass.

pH -- Fluctuations in pH values have been used as an estimate of free-water primary productivity (Hall and Moll 1975). This technique hypothesizes that falling pH reflects an increase in dissolved CO_2 due to plant and animal respiration; increasing pH indicates increasing levels of dissolved oxygen from primary productivity. However, the pH method of estimating primary productivity lacks sufficient accuracy for use in oligotrophic environments such as Lake Huron. Furthermore, for the pH method to be useful, one station must be observed throughout one 24-hour cycle. Finally, pH measurements from different stations at different times of the day are not comparable.

In a well-buffered, oligotrophic system such as Lake Huron, pH changes were expected to be minimal. Tables 4.2-4.7 and Figure 4.12 confirm this expectation. pH changes throughout the year were small: mean surface readings of 7.98 to 8.22. Likewise, areal distributions showed uniformity across the entire lake in all six cruises. These small changes coupled with the problem of readings made at different locations at different times of day prevented any ecological inferences being drawn from the pH data. More meaningful analysis of the pH data came from consideration of pH readings with depth (see below).

Vertical Distribution of Temperature, Nitrogen, Phosphorus, and Silicon

One station representative of each of the four major basins of Lake Huron was used to document the vertical distribution of temperature and nutrients

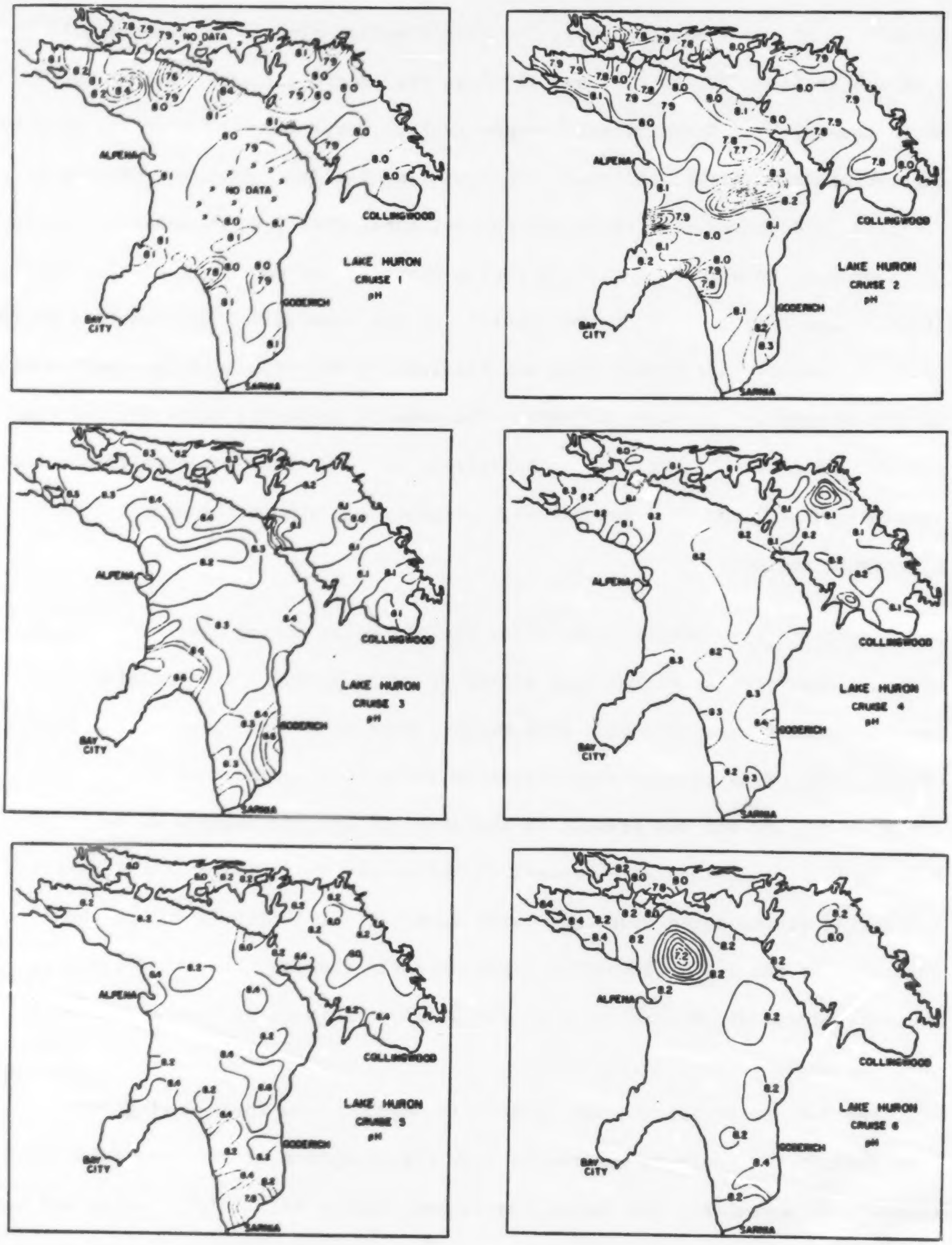

LAKE HURON CRUISE 1 pH
LAKE HURON CRUISE 2 pH
LAKE HURON CRUISE 3 pH
LAKE HURON CRUISE 4 pH
LAKE HURON CRUISE 5 pH
LAKE HURON CRUISE 6 pH
NO DATA
ALPENA
COLLINGWOOD
GODERICH
BAY CITY
SARNIA

Figure 4.12 One-meter pH distribution during 1980.

between April and November 1980. The four stations plotted in Figures 4.13 to 4.16 are stations 15, 44, 78, and 117 from the southern basin, central basin, North Channel, and Georgian Bay, respectively. Results are plotted for temperature, dissolved silica, nitrogen (ammonium ion, Kjeldahl nitrogen, nitrate + nitrite), and phosphorus (total phosphorus, total dissolved phosphorus, orthophosphorus). Data from station 78 (North Channel) are not available for the first cruise (April) because the station was ice covered and inaccessible to the research vessel. Additional data are available from station 15 (southern basin) during January and February of 1981. The results presented below are for one variable at a time rather than by geographic regions; this presentation is used because the vertical profiles for each variable are similar among all four geographic regions.

Temperature -- Thermal conditions in Lake Huron during the April cruise could be described as either late winter or early spring. All locations had inverse thermal stratification with warmer, more dense 4°C water at the bottom of the lake. This inverse stratification was most pronounced at station 44 (central basin), but was present in the other geographic regions as well. Homothermous conditions were present during cruise two (May) at all locations and during cruise three (late May-early June) at all locations except the North Channel. At the latter location, signs of early thermal stratification were present. These signs were an extremely shallow thermocline (5-6 m) and cold surface temperatures (10-11°C).

Thermal stratification was present throughout Lake Huron during cruises four through six (July to November), with the exception of station 78 (North Channel) in November. The thermal cycle was similar in all four basins and was

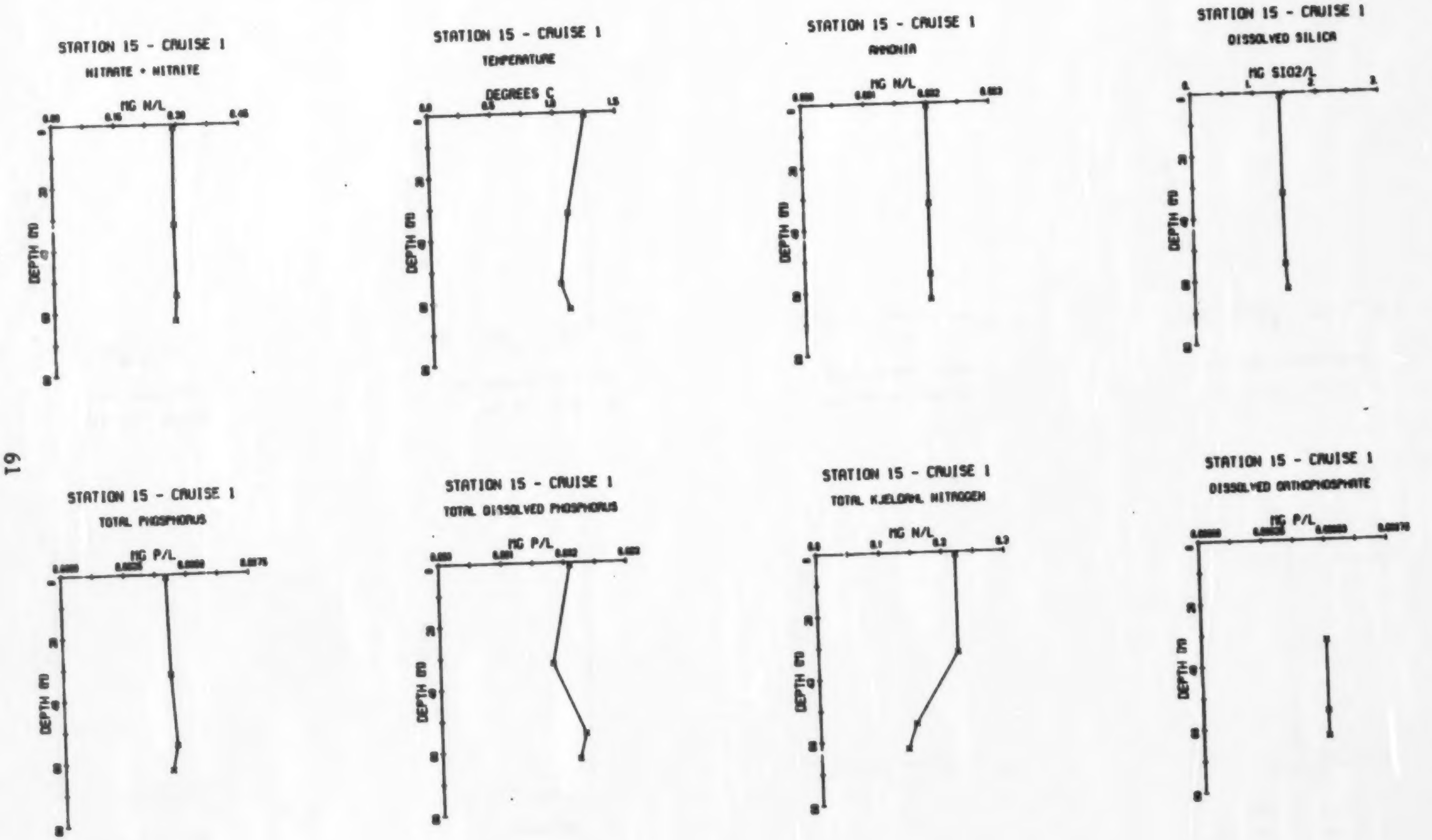


Figure 4.13. Vertical variations of various parameters at station 15.

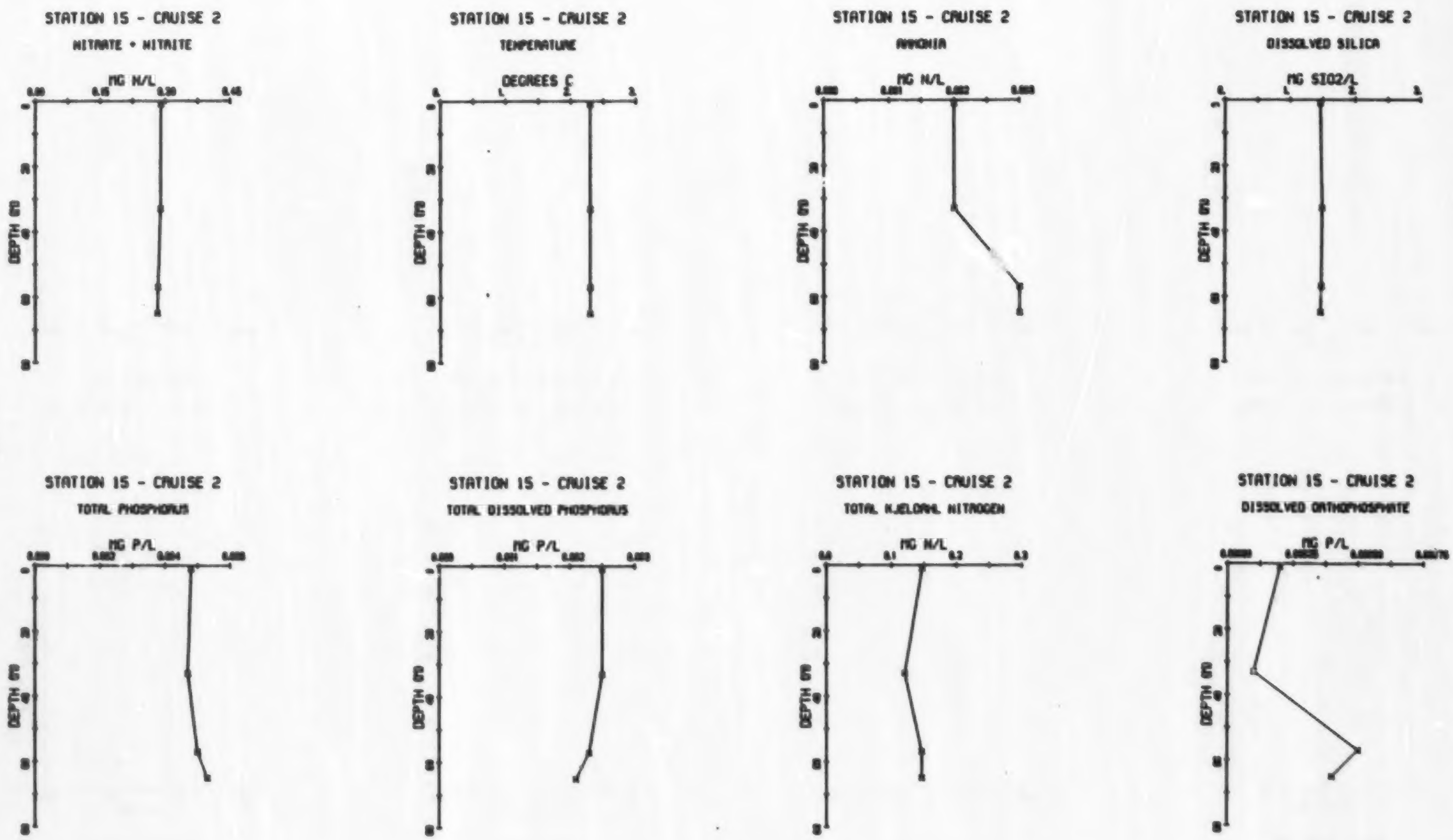


Figure 4.13. (Continued).

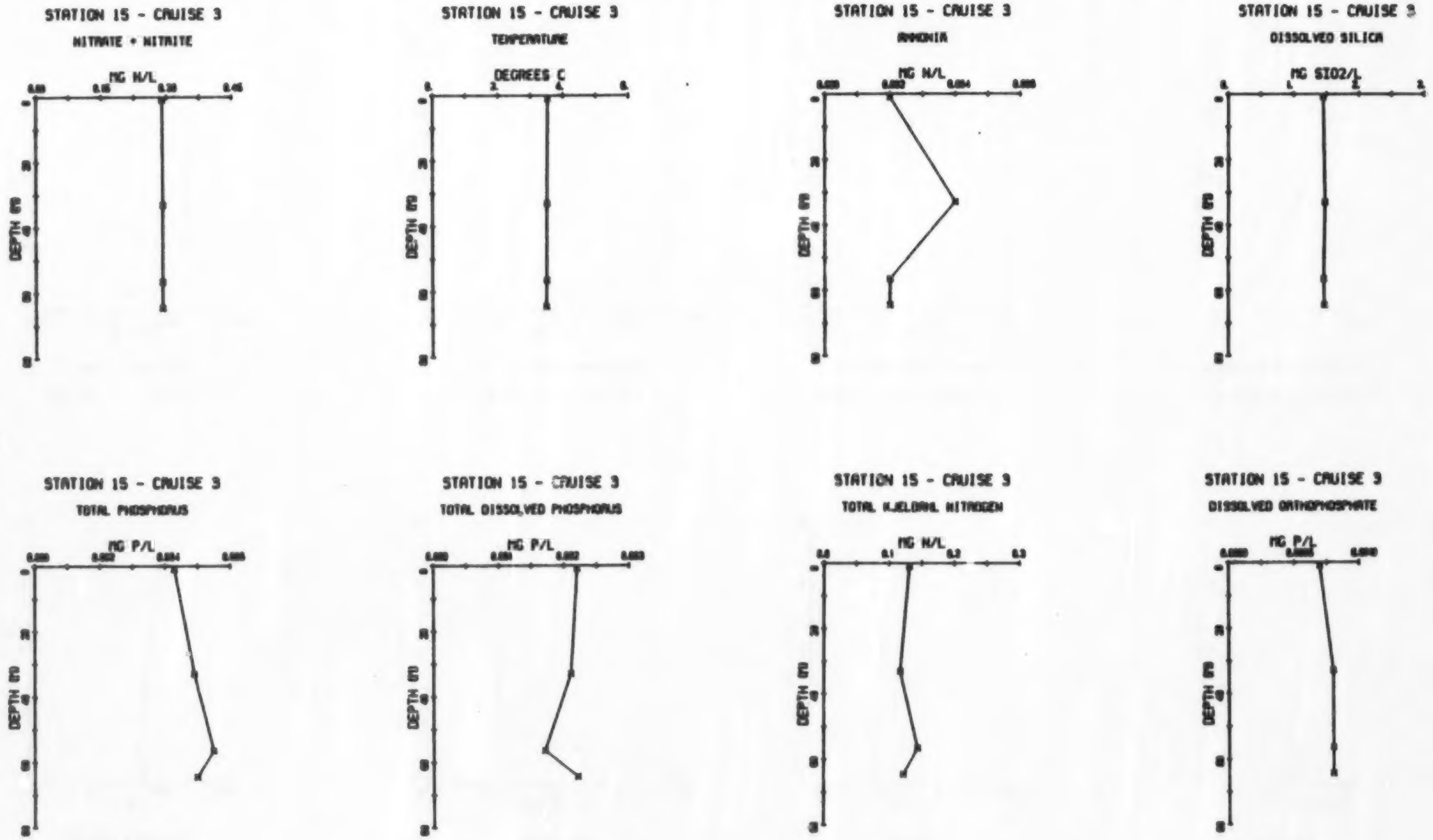


Figure 4.13. (Continued).

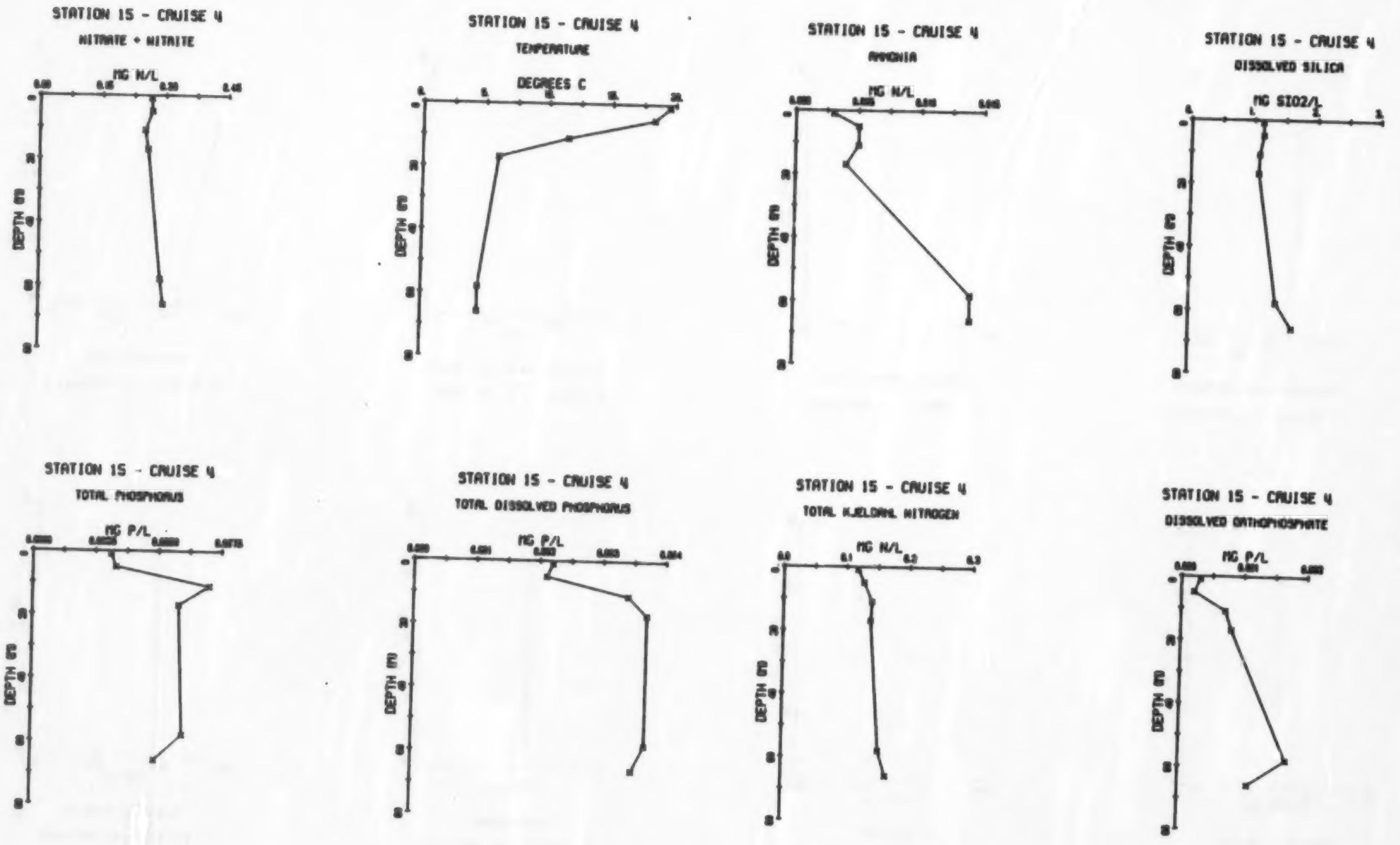


Figure 4.13. (Continued).

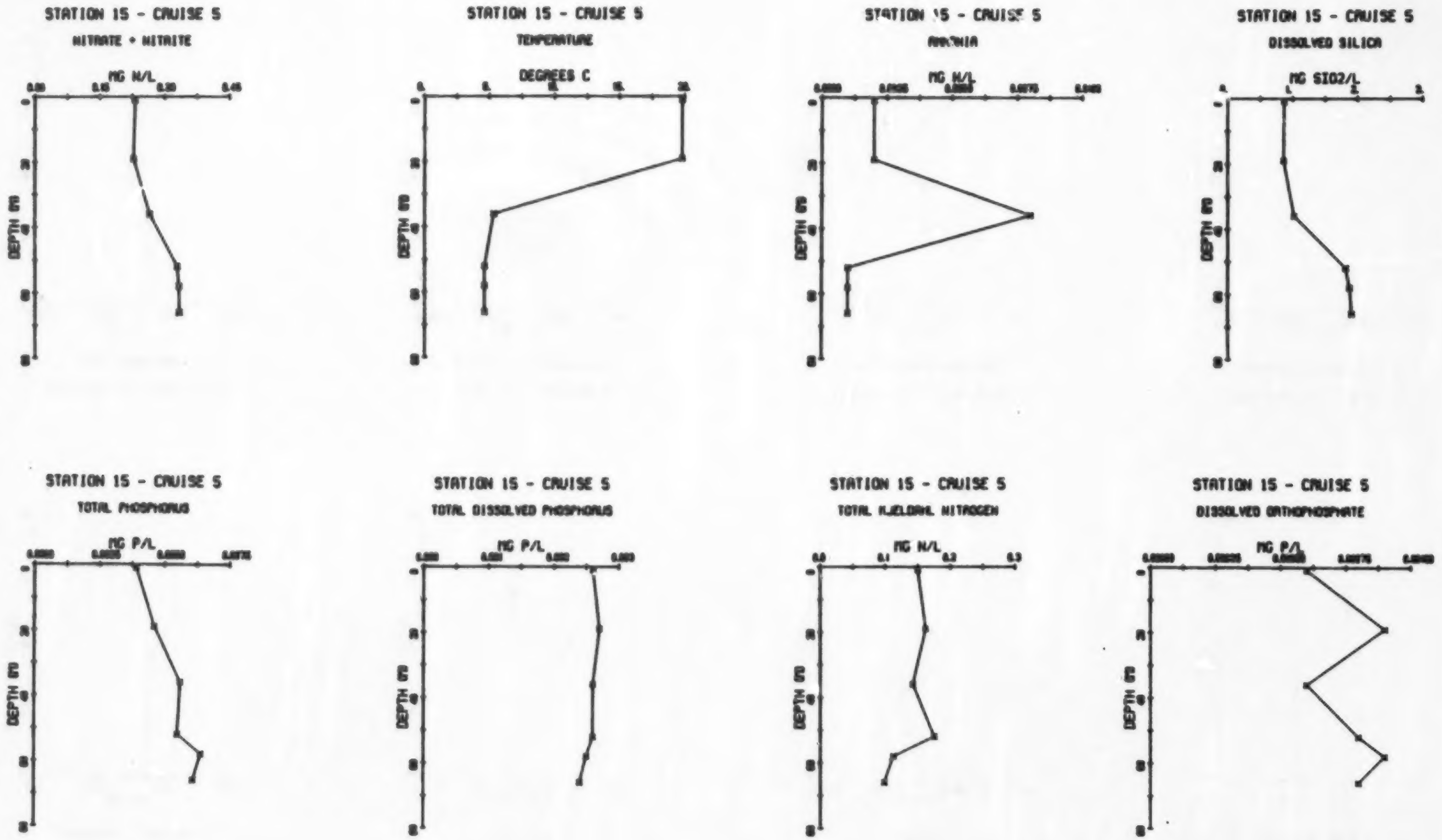


Figure 4.13. (Continued).

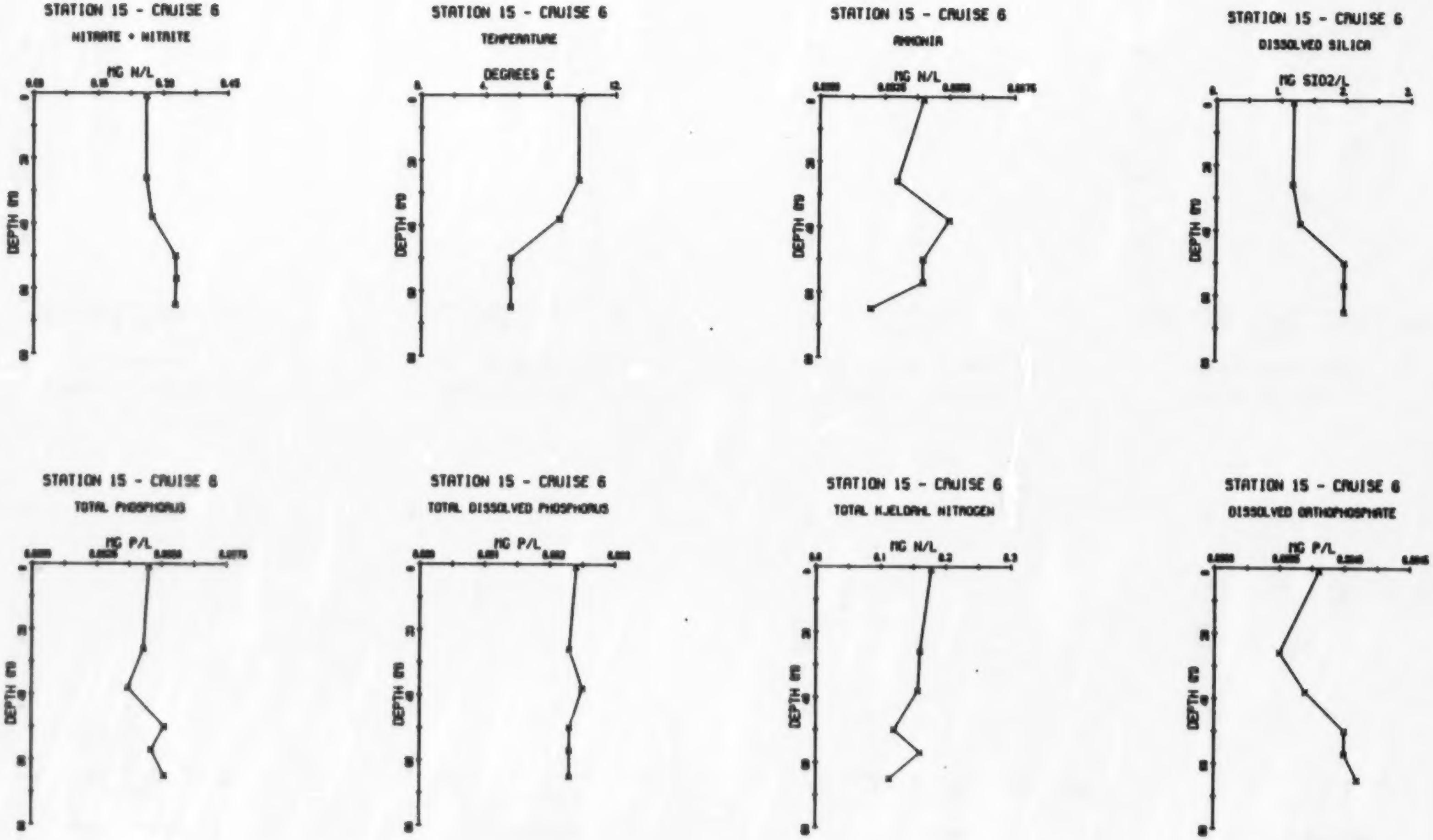


Figure 4.13. (Continued).

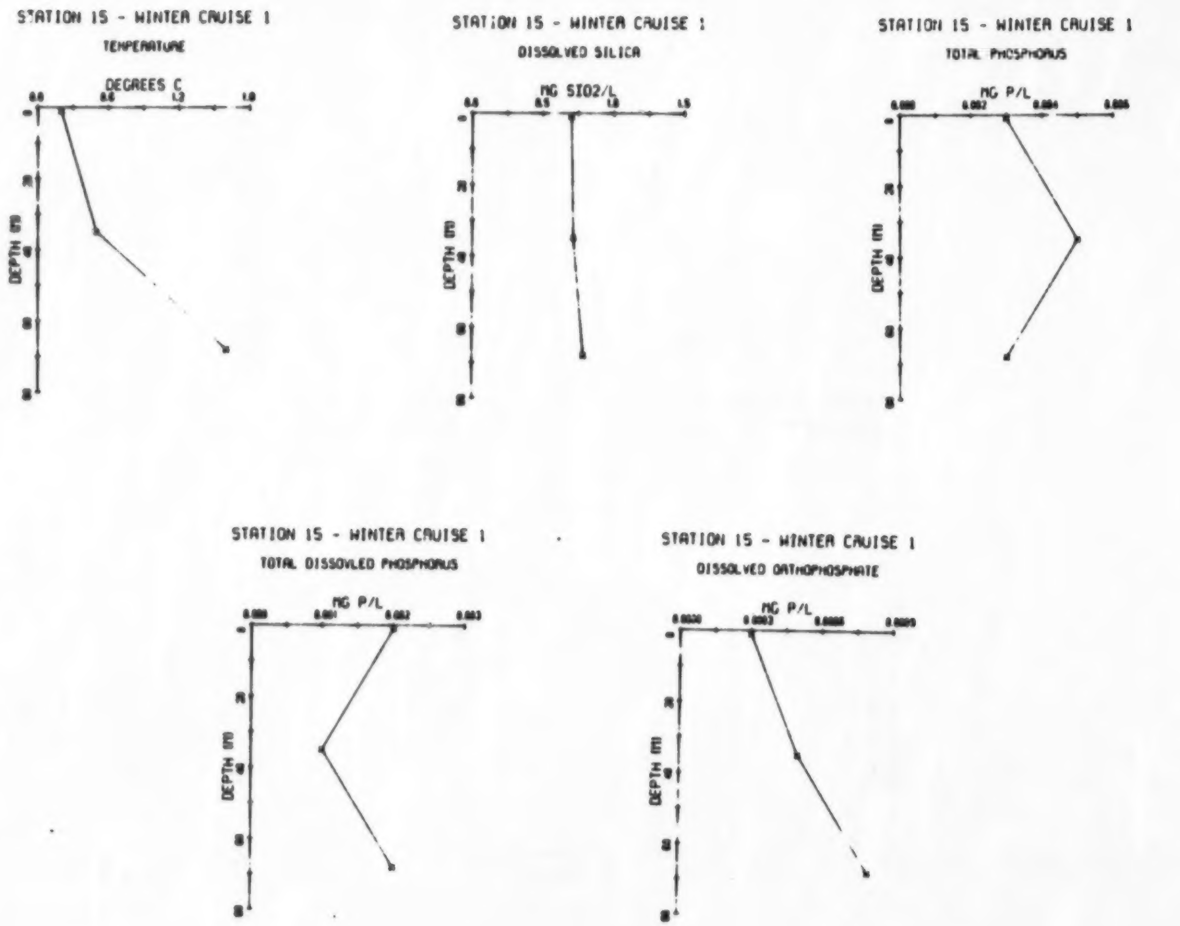


Figure 4.13. (Continued).

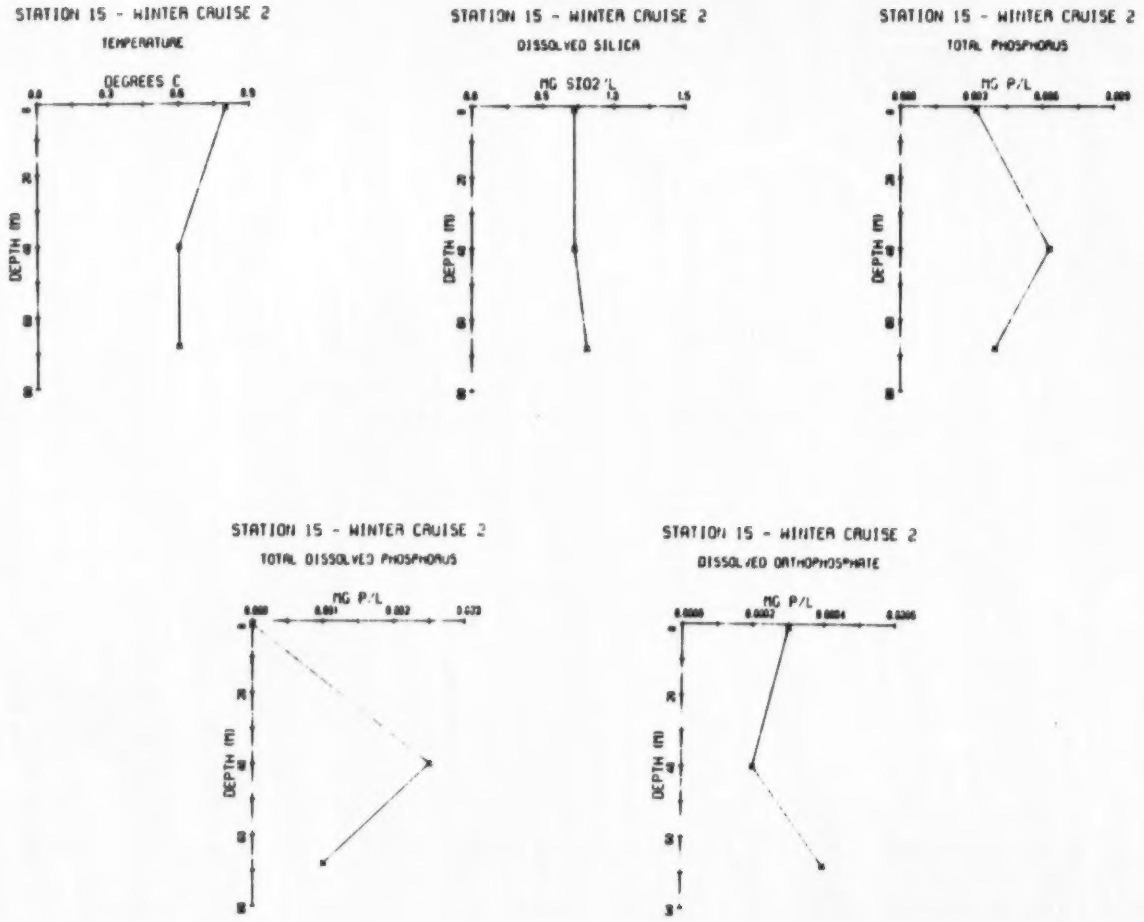


Figure 4.13. (Concluded).

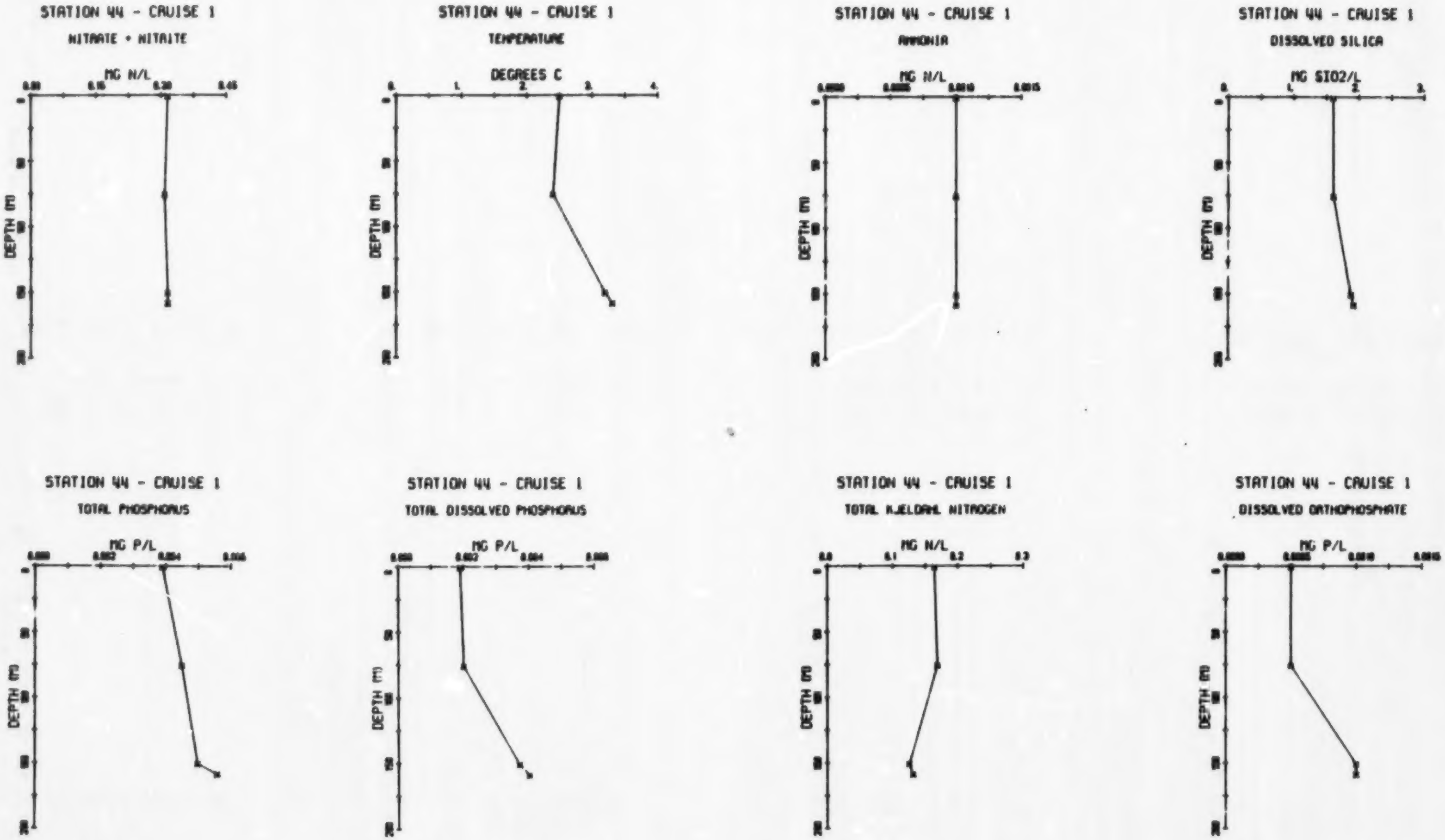


Figure 4.14. Vertical variations of various parameters at station 44.

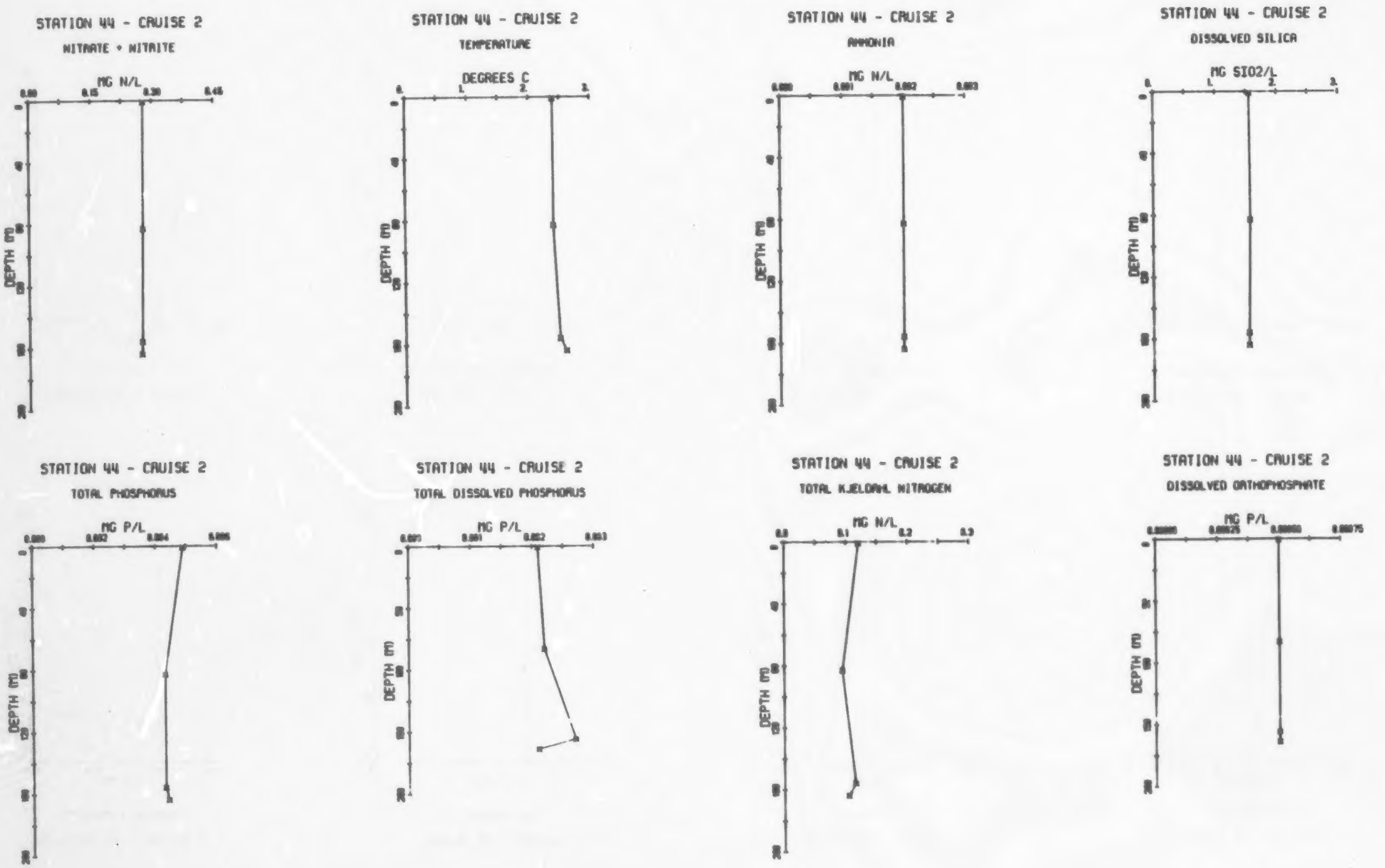


Figure 4.14. (Continued).

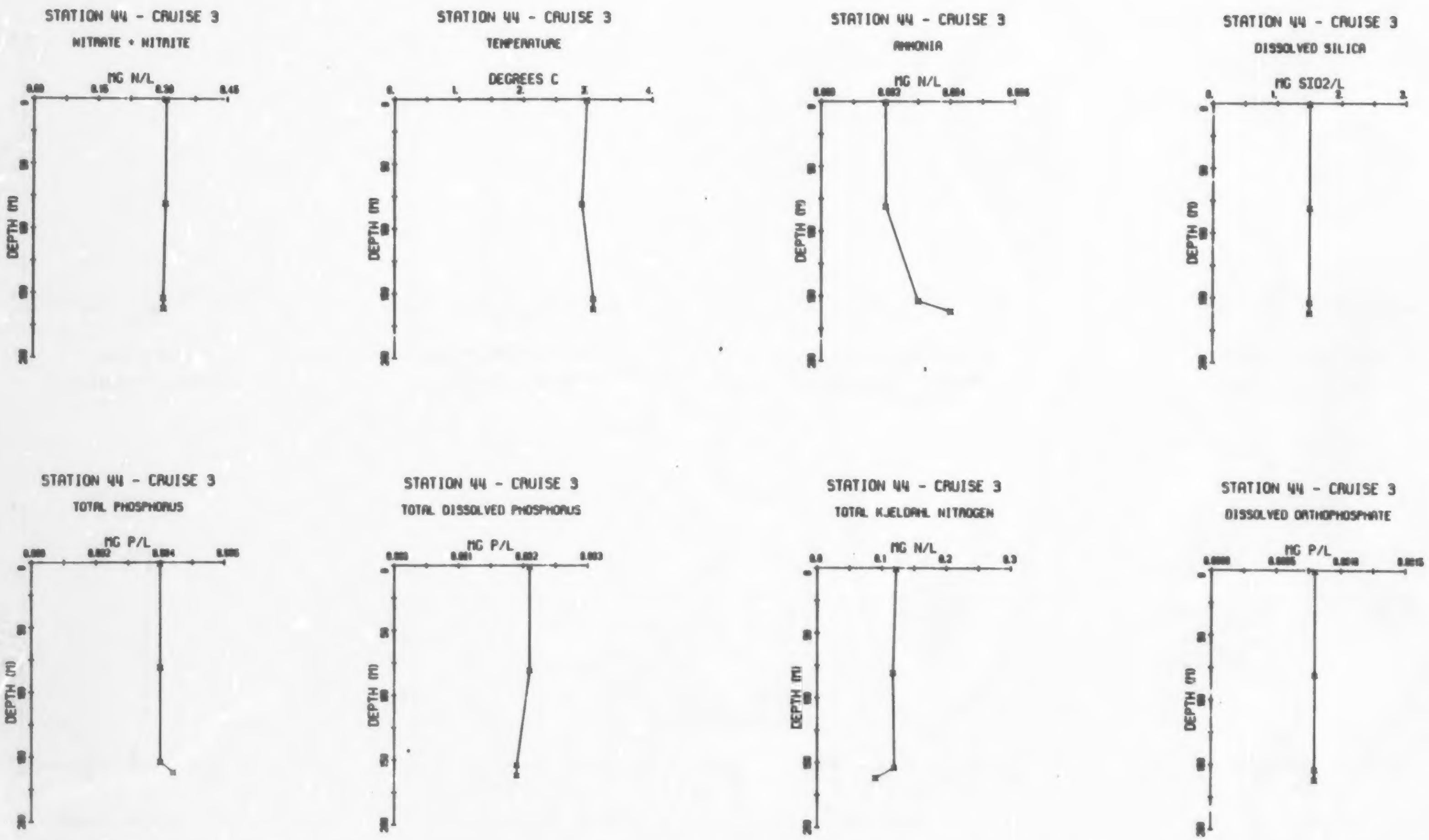


Figure 4.14. (Continued).

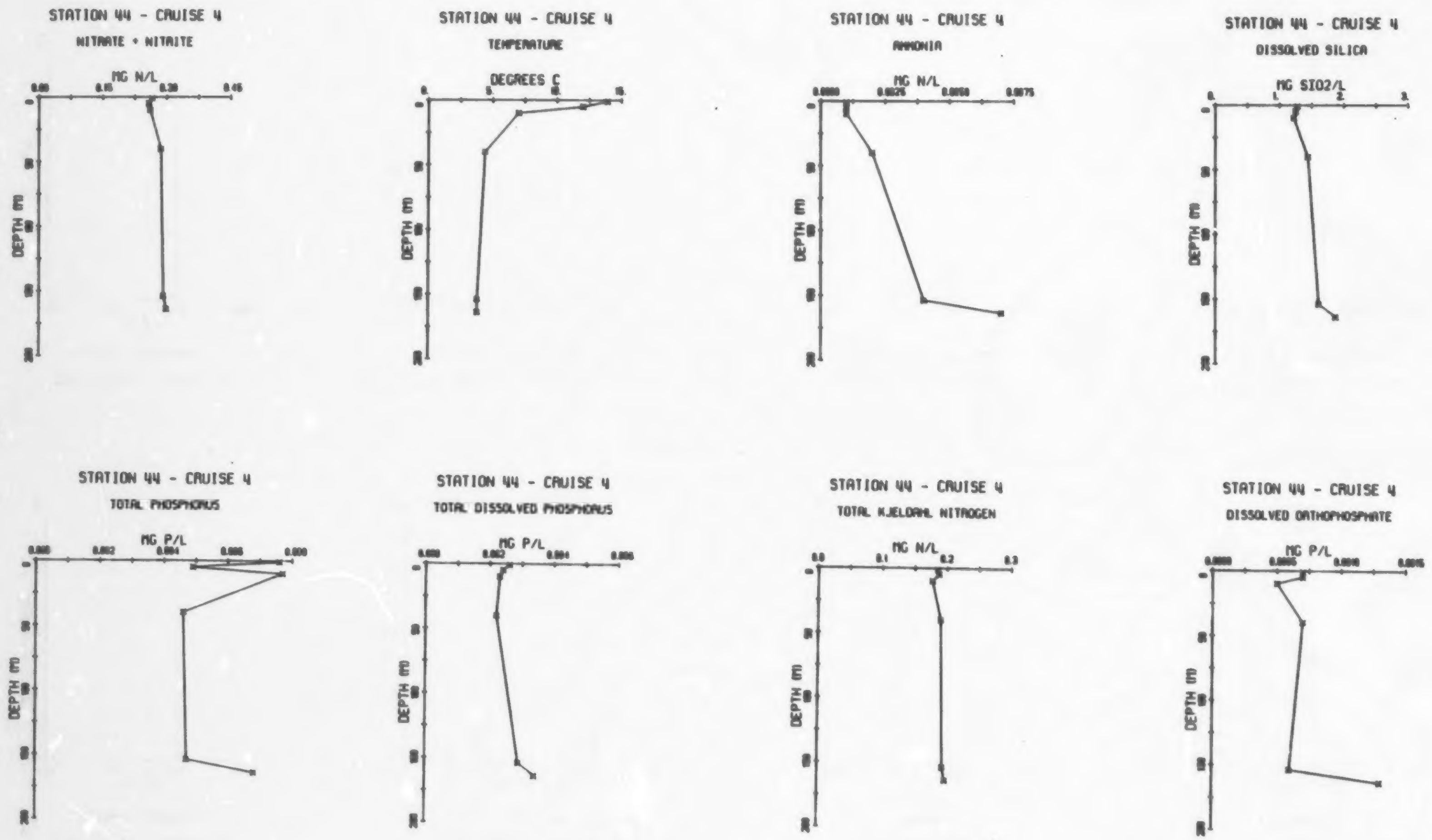


Figure 4.14. (Continued).

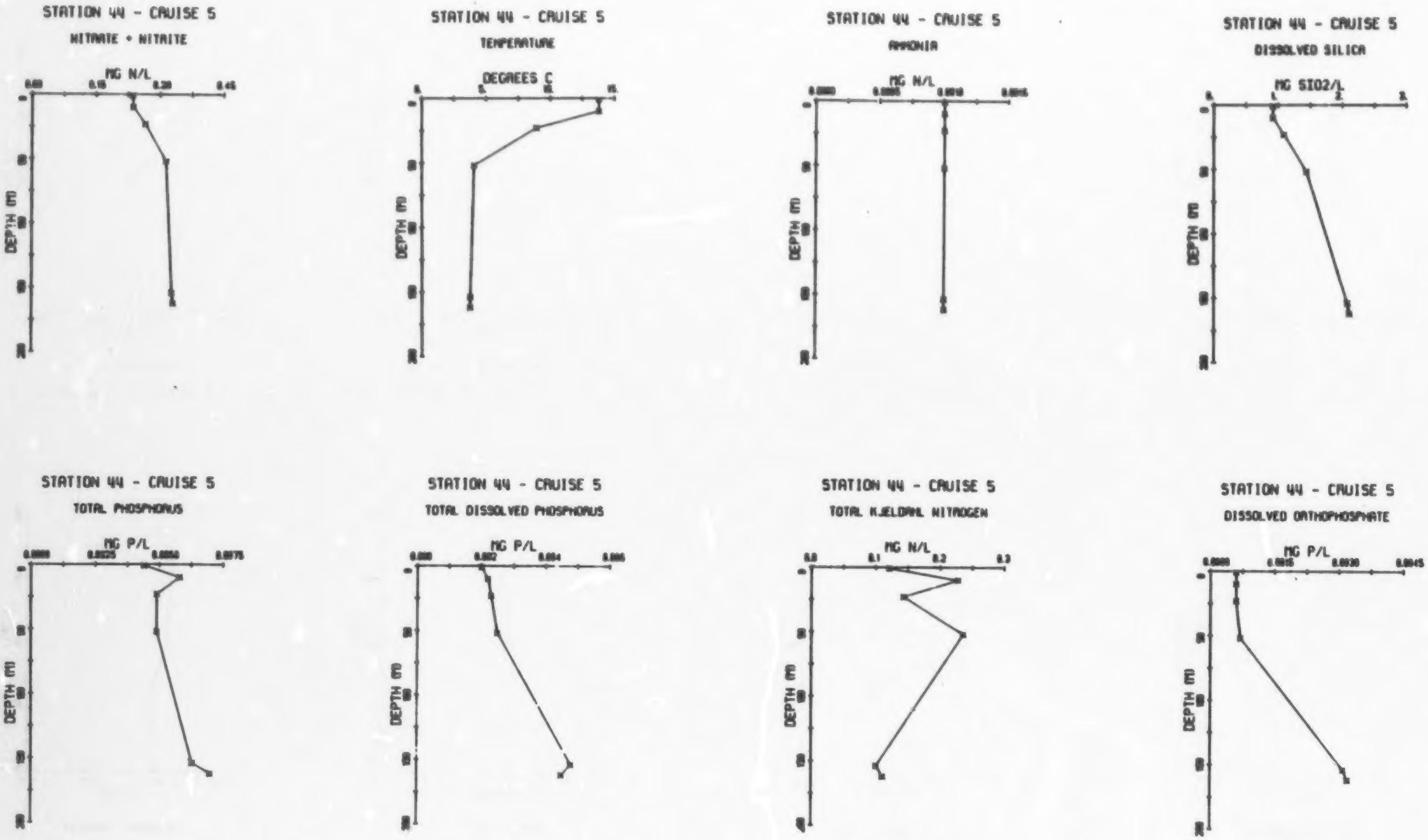


Figure 4.14. (Continued).

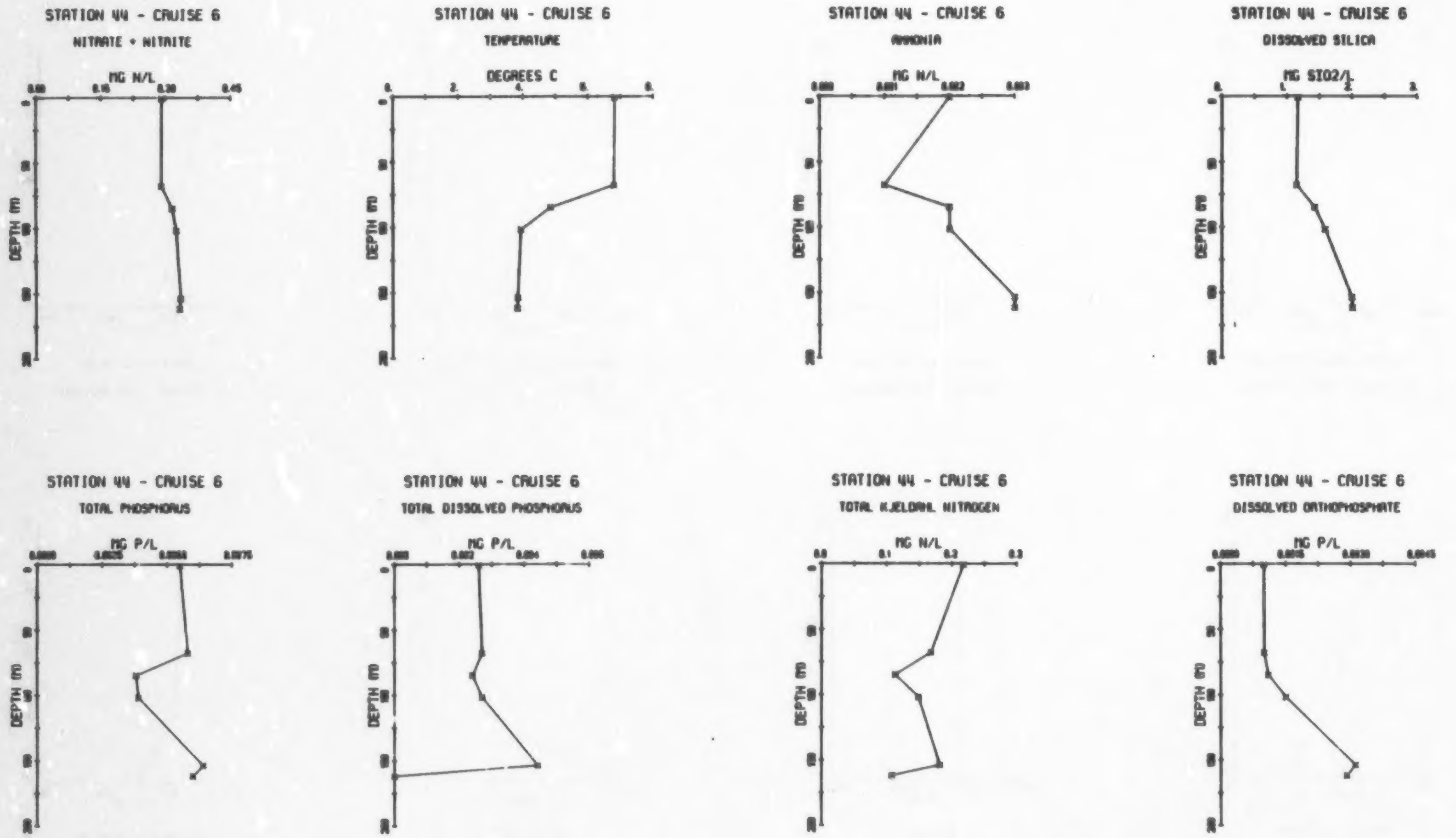


Figure 4.14. (Concluded).

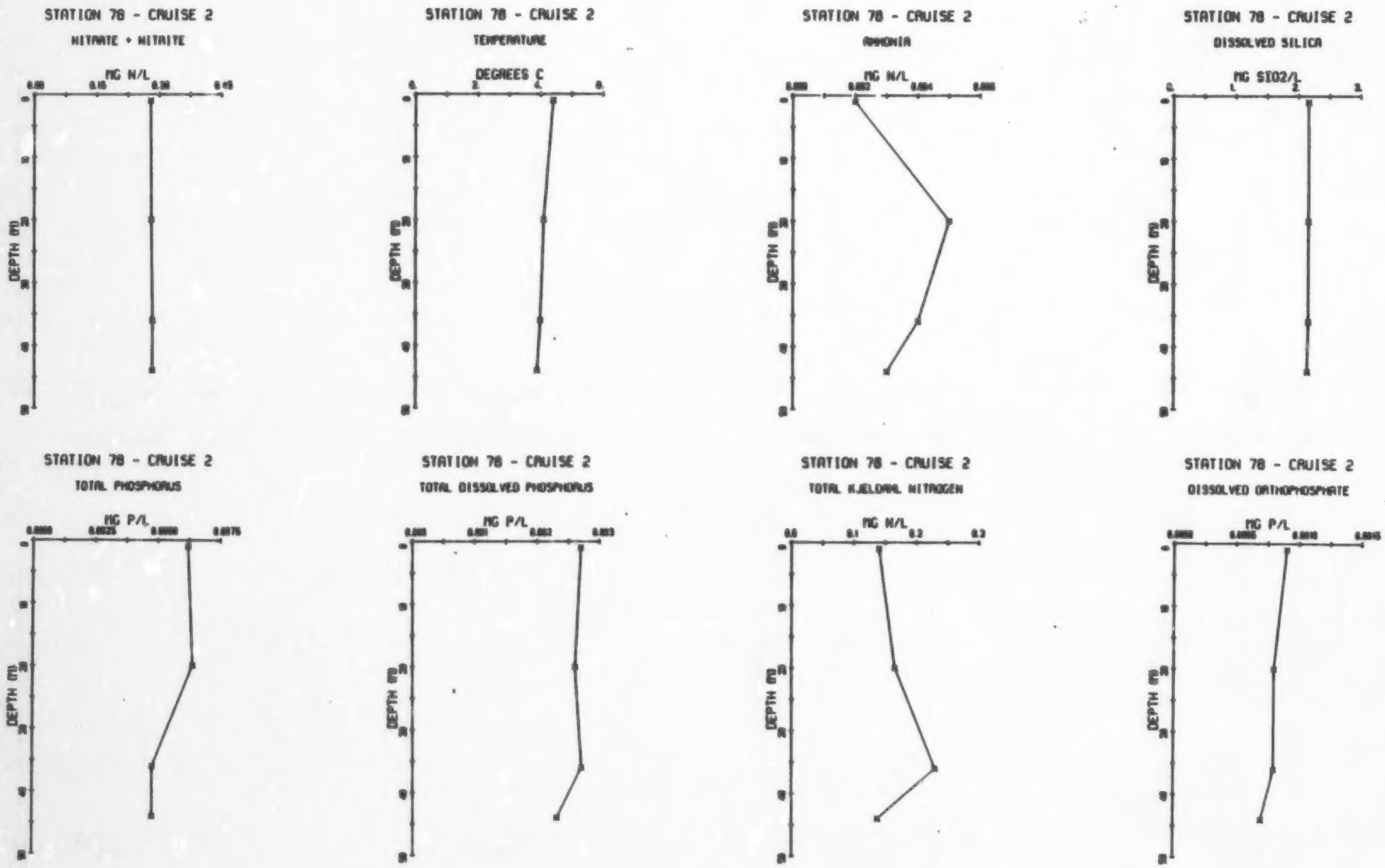


Figure 4.15. Vertical variations of various parameters at station 78.

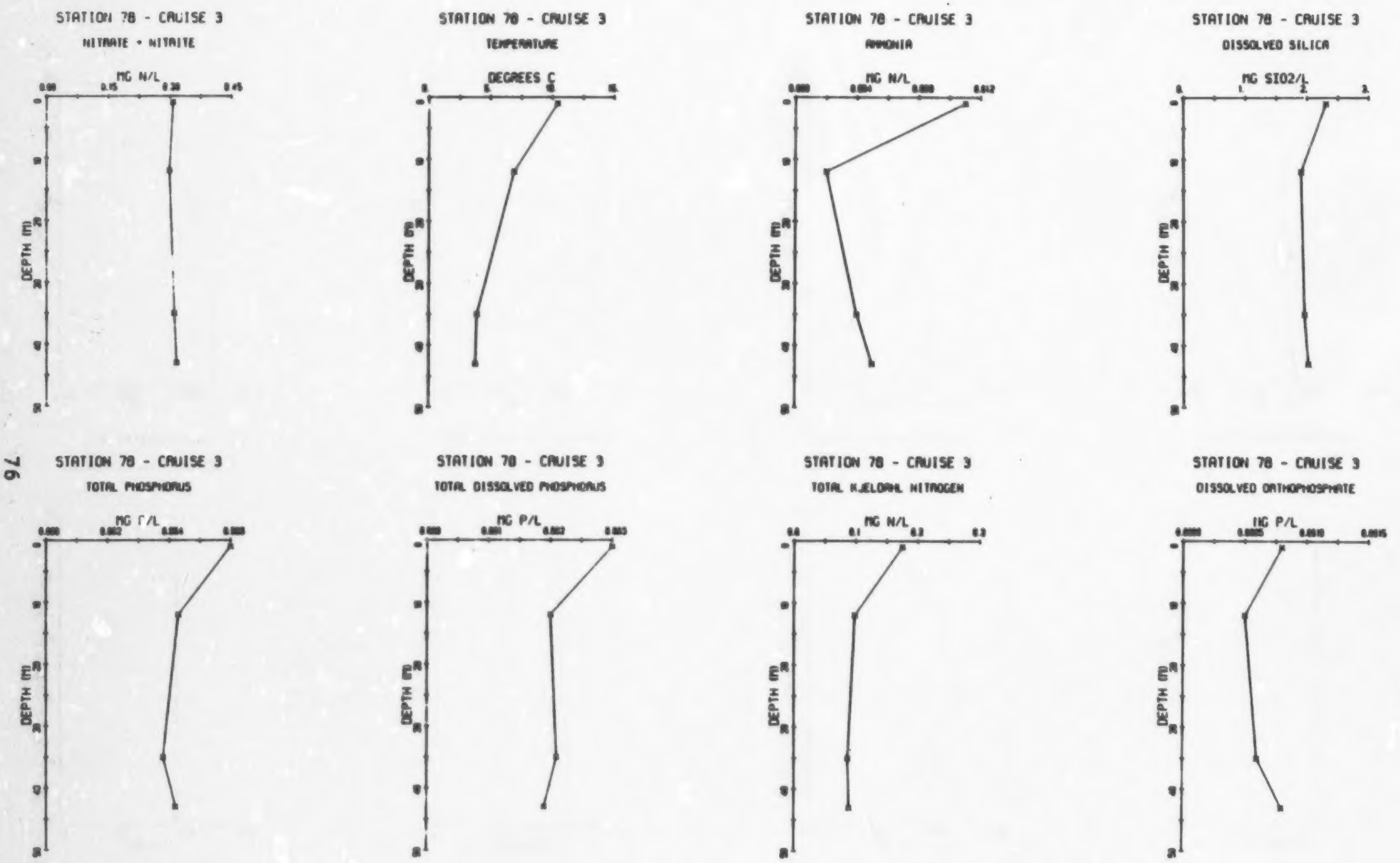


Figure 4.15. (Continued).

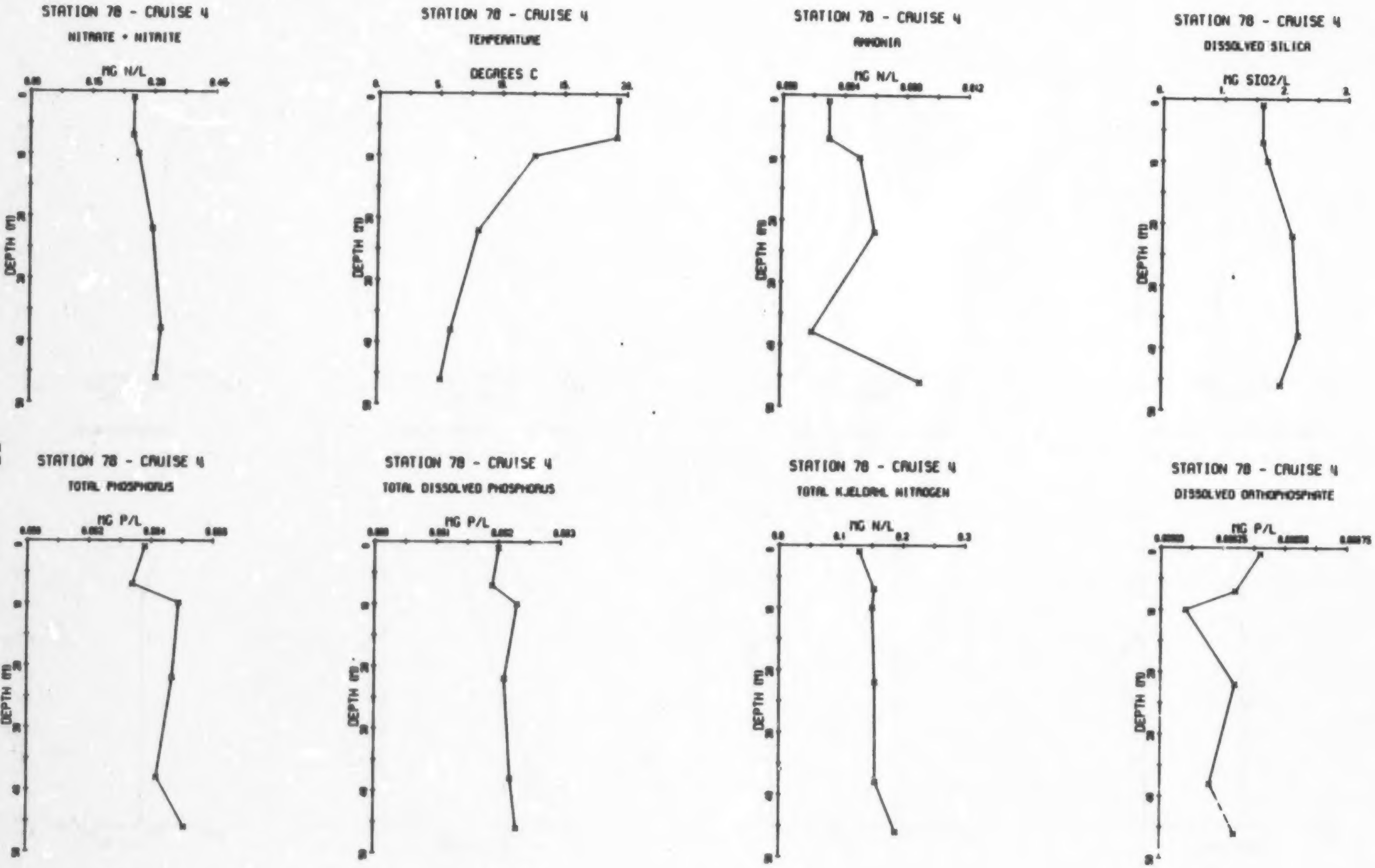


Figure 4.15. (Continued).

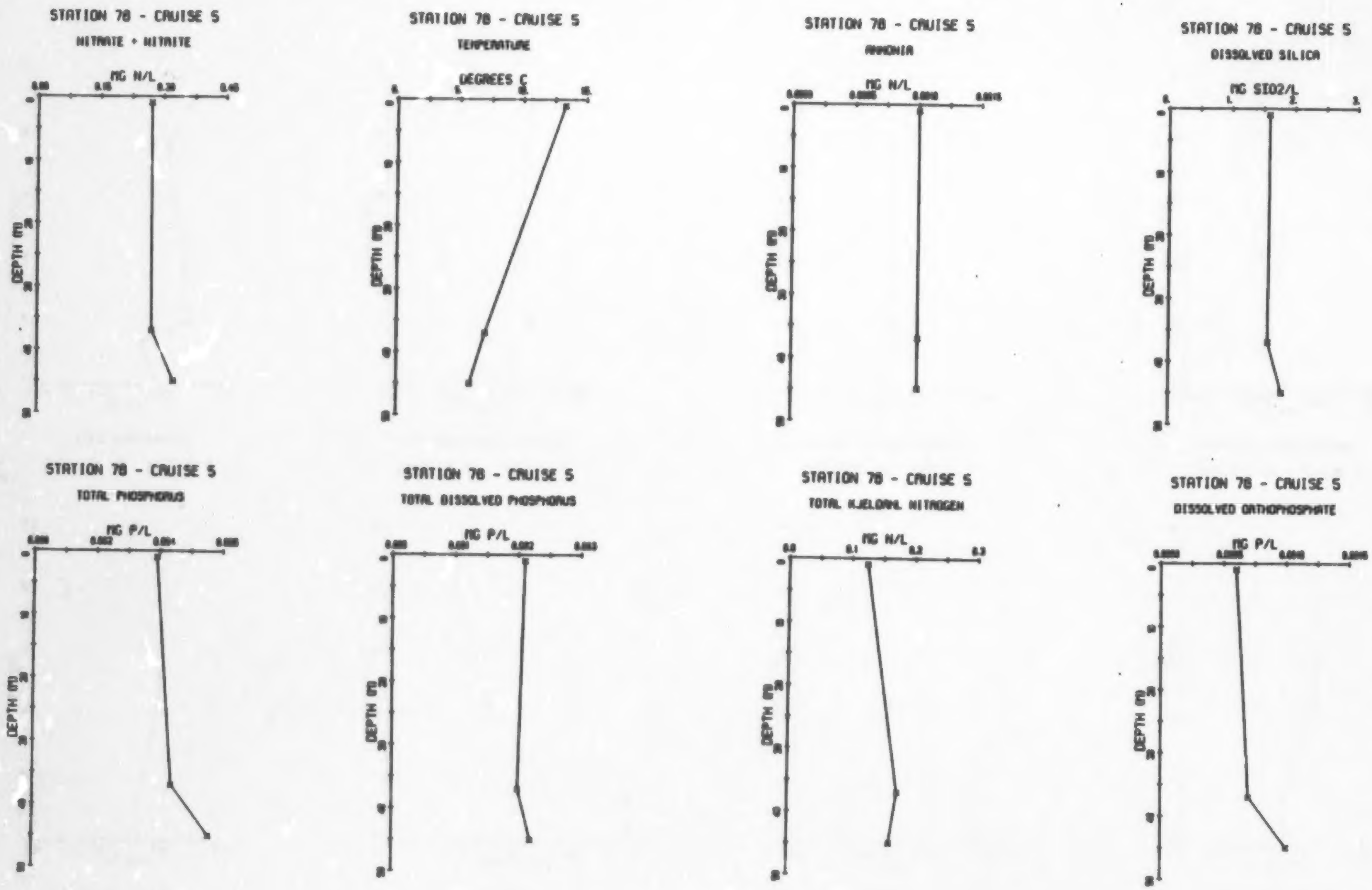


Figure 4.15. (Continued).

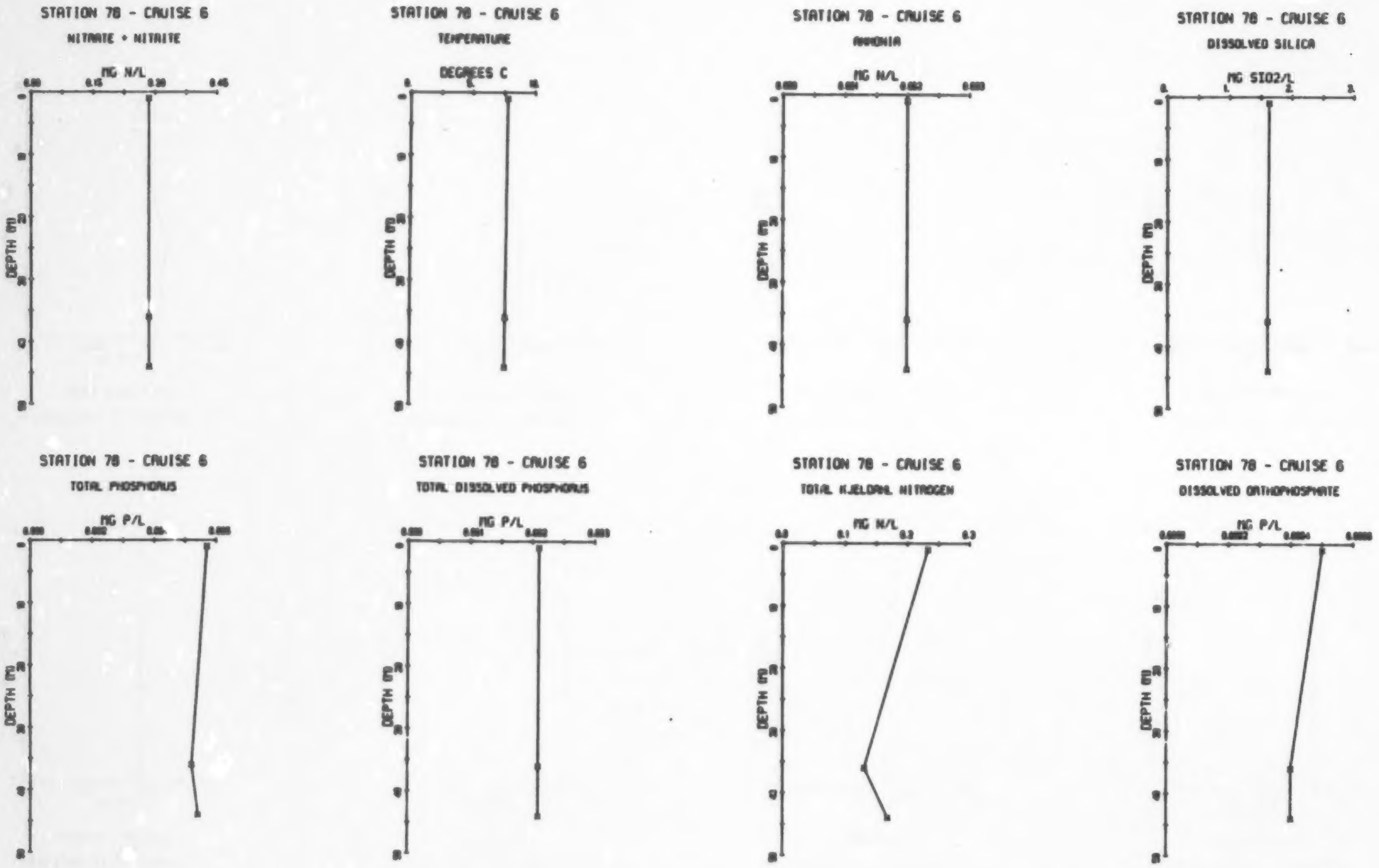


Figure 4.15. (Concluded).

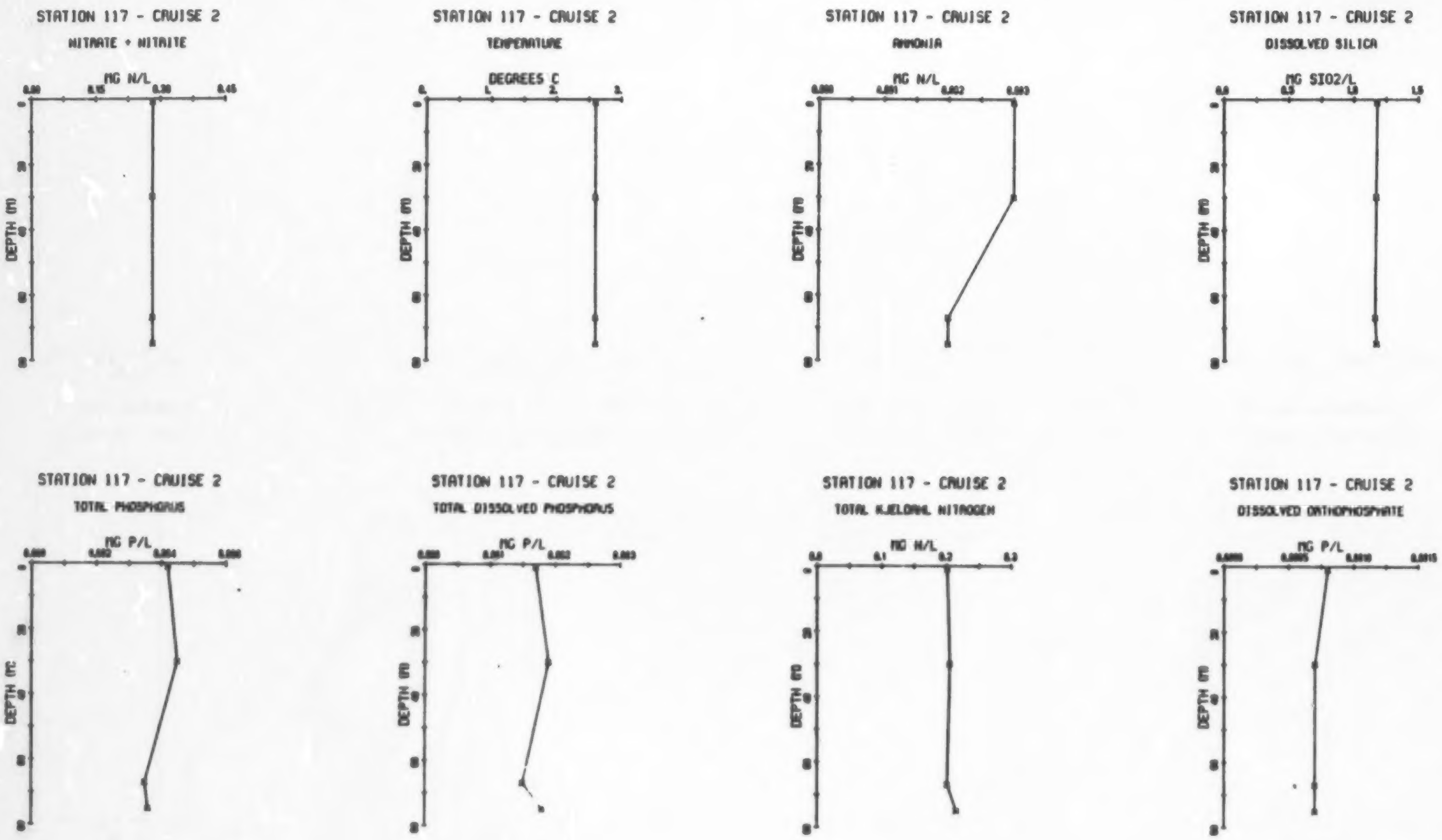


Figure 4.16. Vertical variations of various parameters at station 117.

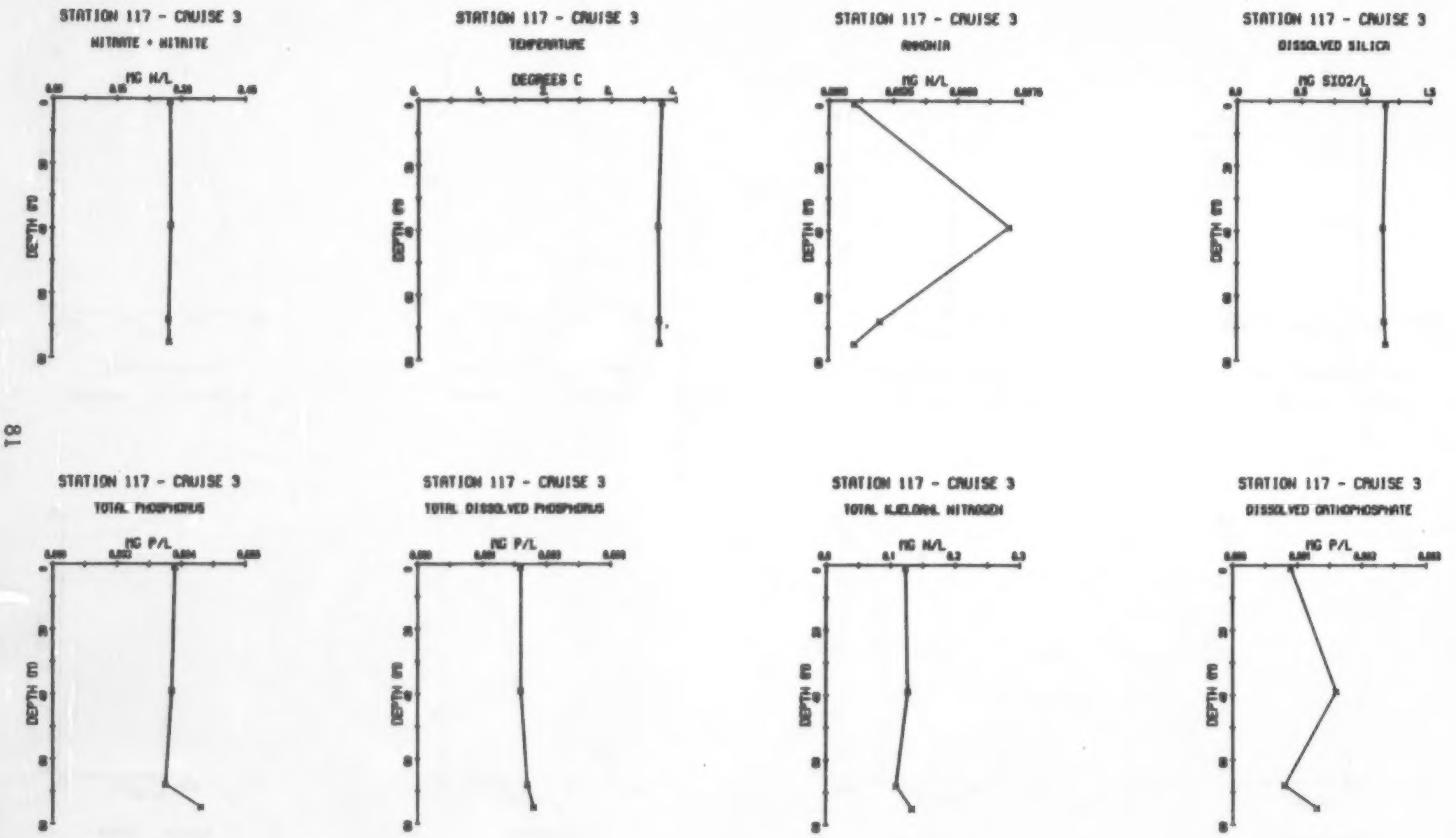
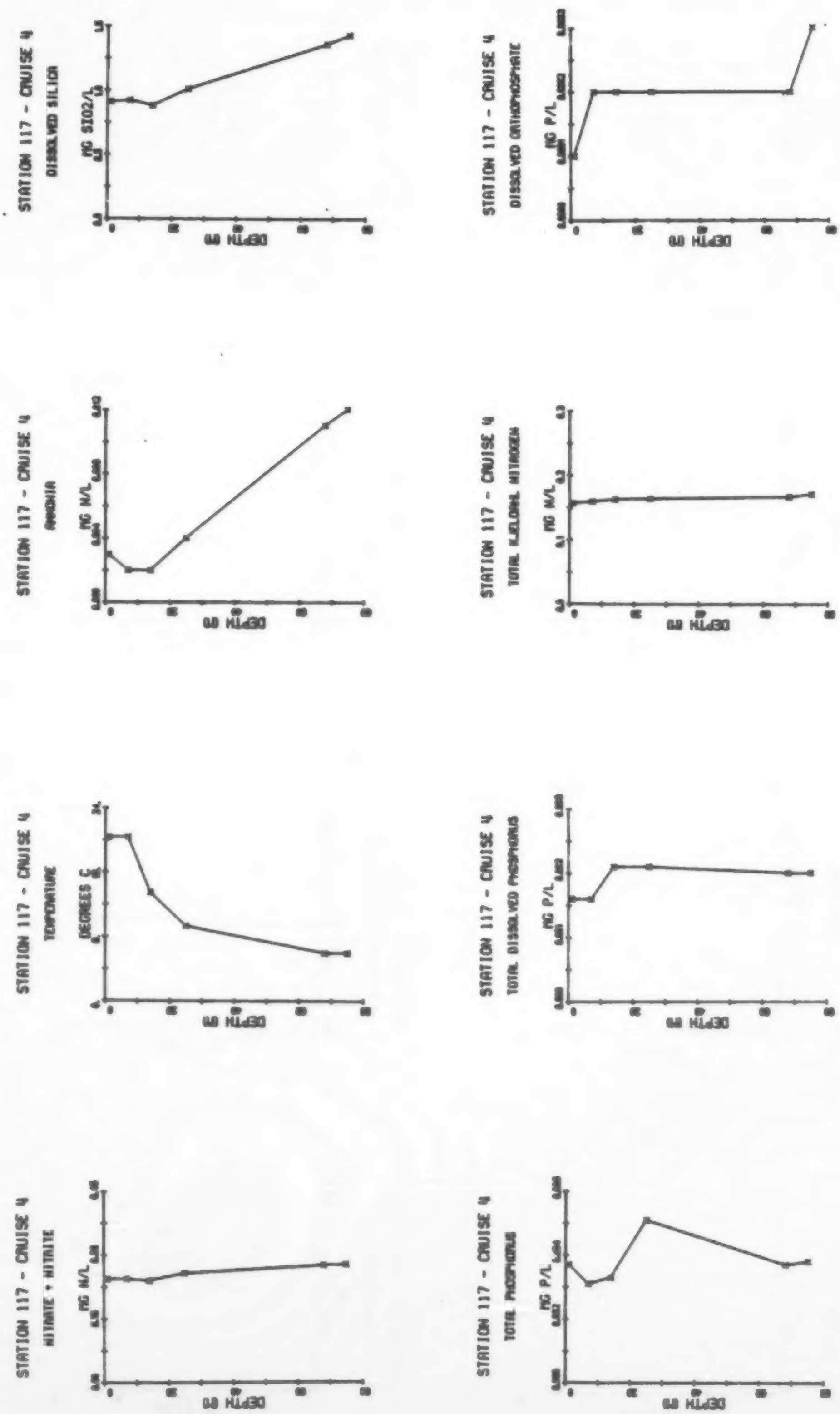


Figure 4.16. (Continued).



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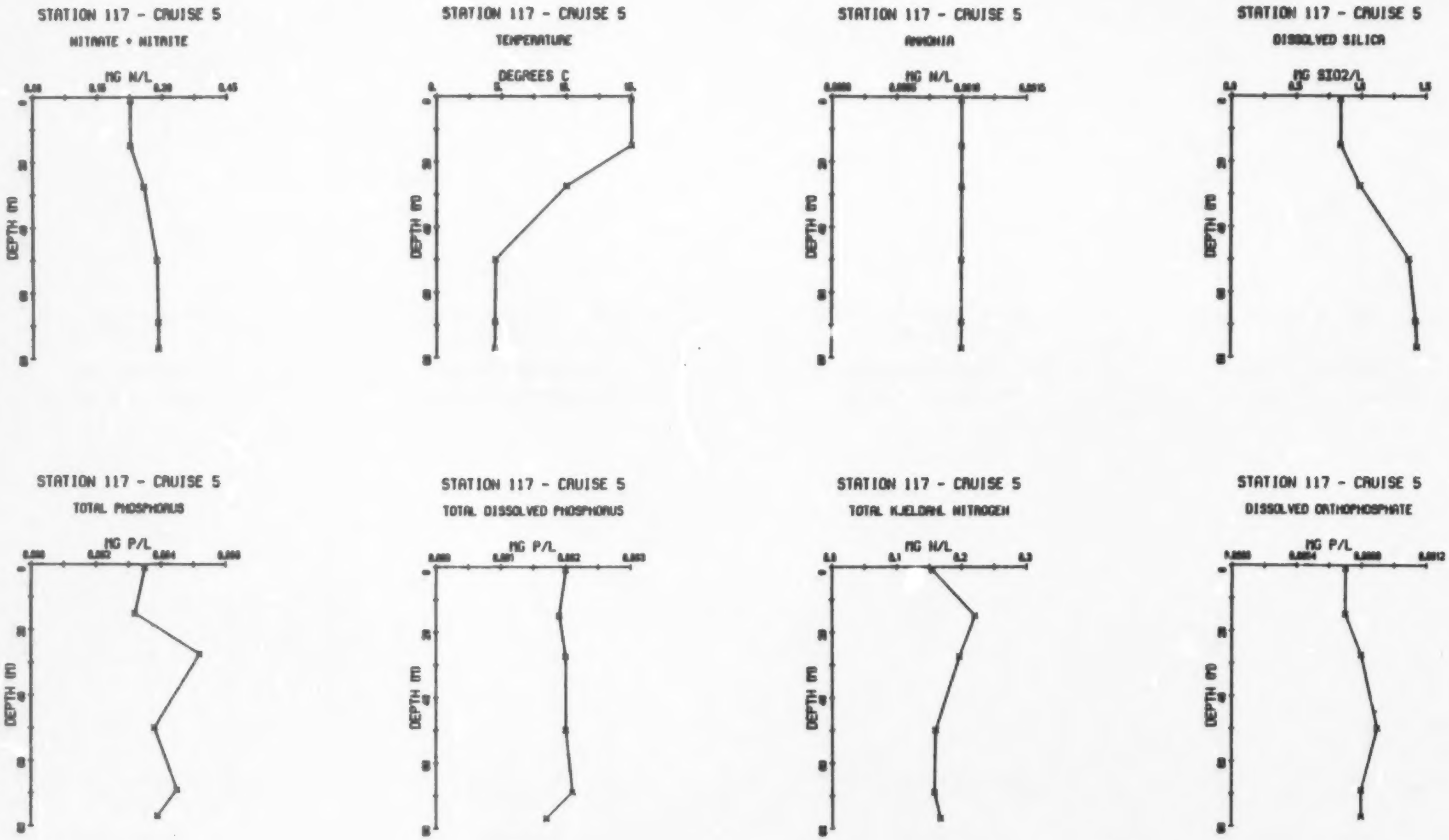

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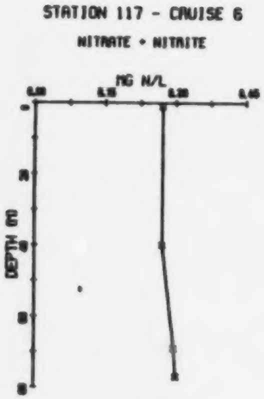

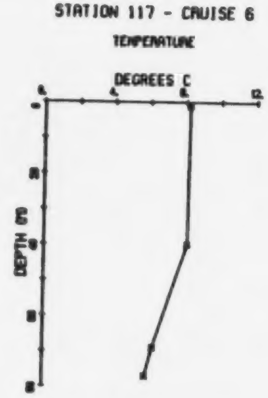

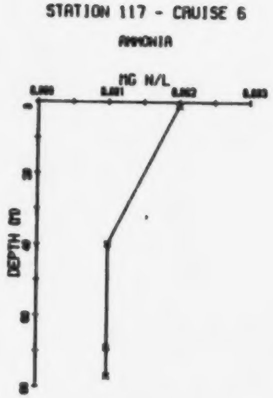

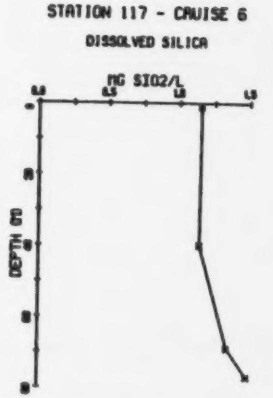

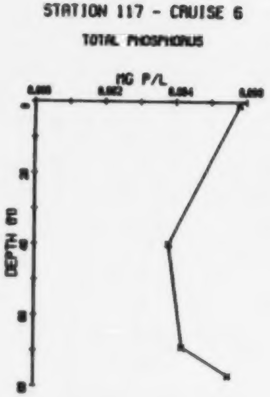

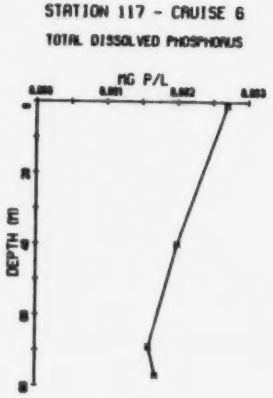

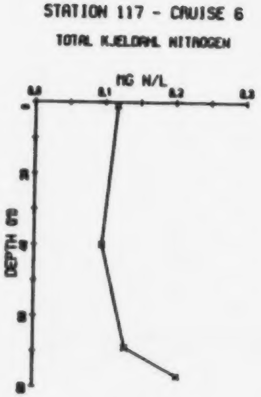

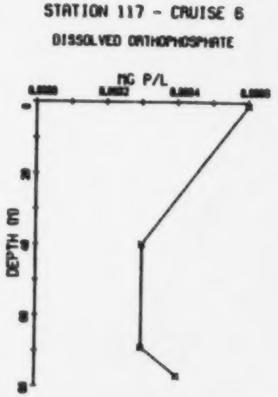

Figure 4.16. (Continued).

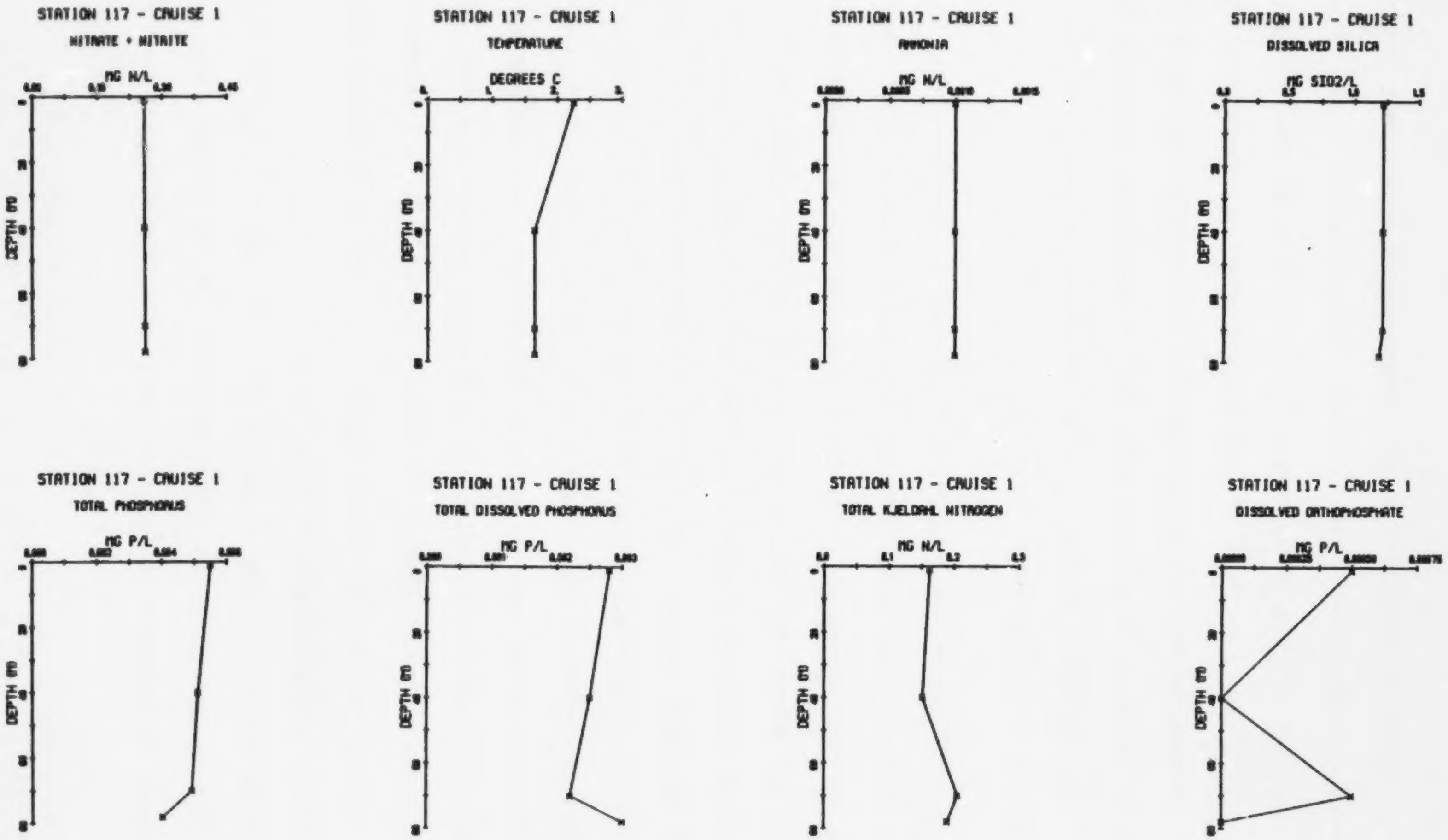

Figure 4.16. (Concluded).

as follows: intense stratification was present during cruise four (July), but the epilimnion was relatively thin (5-10 m). Stratification continued through September, but the epilimnion was much thicker (15-30 m) by cruise five. The epilimnion became very thick in November (50-80 m), although the temperature difference between the epilimnion and hypolimnion was relatively small (5C°). Station 78 in the North Channel had warm (9C°) homothermous conditions in November. The two winter cruises (January and February) in the southern basin showed a return to inverse stratification.

Dissolved Silica -- The vertical distribution of dissolved reactive silica followed a similar annual pattern in all four basins of Lake Huron. During periods of inverse thermal stratification, dissolved silica concentrations were higher near the bottom than at the surface. As the lake became homothermous and was mixed from surface to bottom, dissolved silica became evenly distributed throughout the water column. The onset of thermal stratification created a large difference between surface and bottom dissolved silica concentrations, with surface waters having much lower levels. The difference in dissolved silica concentrations between surface and bottom waters increased from July to September. As Lake Huron cooled during the fall and early winter, dissolved silica was somewhat replenished in the surface waters. But a difference between the lower surface concentrations and higher bottom values persisted through February in the southern basin.

Dissolved silica profiles at station 78 in the North Channel differed slightly from the general trend described above. During cruise three, higher concentrations of dissolved silica were observed at the surface rather than the bottom. Furthermore, dissolved silica concentrations were uniform from the surface to the bottom during cruise six.

The annual cycle of vertical profiles of dissolved silica has been observed in other Great Lakes, most notably Lake Michigan (Schelske and Stoermer 1971, Rockwell _et al_. 1980). The vertical patterns of dissolved silica in Lake Michigan have been attributed to intense silica utilization by diatoms and silicoflagellates (Schelske and Stoermer 1971). The onset of thermal stratification is accompanied by the spring diatom bloom which rapidly utilizes most of the available surface dissolved silica. Algal cells are then transported downward by either sinking or in fecal pellets, increasing near-bottom silica concentrations. This downward flux of silica continues throughout the summer until differences in surface to bottom concentrations are large. These same processes appeared to occur throughout Lake Huron in 1980 because the annual cycle of dissolved silica was similar to that of Lake Michigan. One interesting aspect of the Lake Huron dissolved silica cycle is that a uniform vertical profile was not apparent until just before the onset of summer thermal stratification (Figure 4.13 - Cruise 1 compared with winter cruises 1 and 2).

Dissolved Nitrogen -- Figures 4.13 to 4.16 show that the differences in dissolved nitrogen concentrations (NO_3 + NO_2 and NH_3) between surface and bottom waters are relatively small. Furthermore, dissolved nitrogen was uniformly distributed throughout the water column by cruise one (April) and remained uniformly distributed until cruise four (July). Dissolved nitrogen follows approximately the same annual patterns as dissolved silica for similar reasons; summer phytoplankton growth reduces surface dissolved nitrogen concentrations, while bottom concentrations increase from accumulation of decaying material

(Wetzel 1975). Ammonium concentrations are somewhat more controlled by animal (mostly zooplankton) excretion. Therefore, the vertical distribution of ammonium usually differs from the vertical distribution of nitrate + nitrite during periods of active zooplankton growth. July (cruise 4) was a period of high zooplankton abundances in Lake Huron (Evans 1983). Because nitrogen is usually not a limiting nutrient for algal growth in the Great Lakes (Lin and Schelske 1981), surface nitrogen depletion is rarely as intense as dissolved silica. Nitrogen would not be expected to limit algal growth in southern Lake Huron because of large loadings during the spring runoff (Davis et al. 1980).

Particulate Nitrogen and Particulate Phosphorus -- Total Kjeldahl nitrogen (particulate) had a more irregular pattern of vertical profiles than did dissolved nitrogen. Particulate forms of nutrients tend to have highly variable vertical profiles during periods of thermal stratification (including inverse thermal stratification). Primary production (algal photosynthesis) is the major process that converts dissolved nutrient pools into particulate pools (Wetzel 1975). Once the nutrient has gone through this phase change, a variety of processes affect its distribution as particulate nitrogen and phosphorus. These processes include sinking, advection, grazing, and regeneration. Because each of these processes can dominate particle dynamics at different locations and times, the vertical distributions of particulate nitrogen and phosphorus in Lake Huron are usually non-uniform and highly variable. In general, processes affecting particulate phosphorus and nitrogen pools are important only during periods of high primary productivity (spring and summer). As a result, vertical profiles of particulate nitrogen and phosphorus showed no change among the early spring cruises (one to three) and large differences among the late spring and summer cruises (four and five).

Phosphorus -- The vertical distributions of dissolved orthophosphate and total dissolved phosphorus followed a pattern similar to dissolved nitrogen. The distribution of soluble phosphorus was uniform during homothermous conditions (May and June). During stratified conditions, phosphorus concentrations were always lower in surface waters than in bottom waters; this surface to bottom difference was also present during periods of inverse thermal stratification.

Dissolved phosphorus is usually regarded as the limiting factor for algal growth in Lake Huron (Lin and Schelske 1981). As a result, this nutrient is almost always at low concentrations and rapidly recycled throughout the epilimnion. Available phosphorus pools are small and rapidly utilized. These processes keep phosphorus concentrations uniformly low throughout the water column, and reduce the magnitude of the surface to bottom differences in dissolved phosphorus concentrations. The vertical profiles of dissolved and total dissolved phosphorus in Lake Huron (Figs. 4.13 to 4.16) show relatively uniform distributions but low concentrations.

Conservation of Nutrient Mass -- The processes of advection and primary production can serve to cause overall seasonal depletion of a nutrient in one region of Lake Huron. The mechanisms work as follows: Photosynthesis causes a major shift from the dissolved to particulate phase of most nutrients in the summer. Currents could then move the particulate nutrients away from the regions of high photosynthesis. The net result is a local, seasonal depletion of nutrients. This process can be partially evaluated by comparing the water column total for each nutrient among the six cruises. Figures 4.13 to 4.16 show that the only region of net loss or gain was for dissolved silicon at station 78 (North Channel). This station shows a net loss of dissolved silica between cruises two and six.

Summary

The limnology of Lake Huron during 1980 indicates two major properties of the ecosystem: this is an oligotrophic ecosystem, and the lake has several important external inputs of nutrients. The oligotrophic characteristics of the ecosystem are reflected in two ways. First, nutrient concentrations were low in 1980, compared to most other lakes, indicating low levels of internal and external loadings. Second, the annual ranges of most nutrients were small. These small ranges suggest small seasonal loadings which in turn stimulate small algal crops.

The external inputs to Lake Huron take several forms based on location and season. Water from Lakes Michigan and Superior flow into Lake Huron and mix in the vicinity of the North Channel and Straits of Mackinac. These waters tend to have contrasting properties, and Lake Huron ultimately takes on characteristics as a mixture of the two water masses. Georgian Bay is often dominated by runoff from rivers flowing across the Canadian Shield. Southern Lake Huron is a mixture of water from outer Saginaw Bay, central Lake Huron, and runoff from the Ontario shore. Each of these three inputs to southern Lake Huron tends to dominate the southern basin in a different season.

CHAPTER FIVE

SPATIAL DISTRIBUTION OF DISSOLVED NUTRIENTS: A COMPARISON BETWEEN 1980 AND 1974

by David C. Rockwell

Introduction

Water quality in Lake Huron, Georgian Bay, and the North Channel has a large amount of spatial variability which is due, in part, to nearshore nutrient loadings and discharges from Lakes Michigan and Superior. Lake-wide average concentrations of most nutrients usually have large variances because of this spatial heterogeneity. Fixed geographical areas are compared in this chapter because water quality is evaluated in this manner by the public. Identification of environmental changes within fixed areas is a conservative measure of change because small magnitude changes may be missed due to the inherently larger variances associated with fixed geographical area analysis relative to the homogeneous water mass approach (see Chapters 6 and 8). By dividing Lake Huron, Georgian Bay, and the North Channel into 19 open lake and 8 nearshore areas, different areas in 1980 were compared with one another; and the 1980 areas were compared with their 1974 counterparts to detect gross changes between the two years. A statistical comparison of the surface layer or epilimnion (S/E layer) with the lower layer or hypolimnion (L/H layer) samples for the major nutrients, specific conductivity, pH, and alkalinity is contained in Appendix A. Statistically significant differences between S/E and L/H means were determined when the limnion 95% confidence intervals did not overlap. Appendix B contains statistical summaries of the nearshore areas and the open lake areas for the 1974 and 1980 seasons.

1974 Segmentation of Lake Huron

During the analysis of the 1974 Lake Huron surveillance data, a scheme of segmenting the lake was devised in an effort to reduce variance components associated with average nutrient concentrations. In this scheme, Lake Huron, Georgian Bay, and the North Channel were divided into 19 segments, each of which was considered a relatively "homogeneous water mass" (IJC 1976, 1977). Each segment was a compact geographic region with similar water quality (Fig. 5.1). Nearshore waters of Lake Huron, the North Channel, and Georgian Bay were divided into nine segments A to I (Table 5.1). Saginaw Bay segment H was not considered in the analysis of the 1980 data. Nearshore waters were defined in 1974 as a water column with a depth of 15 m or less and/or within 3 km from the nearest shore. Open waters were geographically segmented into 19 areas, with area 3 covering parts of the North Channel and Georgian Bay (Table 5.2). Open waters were defined as greater than 3 km from shore and/or a water column deeper than 15 m in depth. Seasons for 1974 were defined as spring (April, May, June); summer (July, August, September); and fall (October, November, December). Cruises 1 through 3 were considered spring, cruises 4 and 5 were summer, and cruise 6 was fall. Epilimnetic waters were defined as the upper 10 m of the water column in 1974. This definition was convenient in the nearshore areas. In deep water areas, the vertical sampling pattern seldom placed more than the 1-m sample in this layer.

1980 Segmentation of Lake Huron

Comparison of 1980 results with 1974 results was conducted by dividing the nearshore and open water areas of Lake Huron into segments similar to the 1974

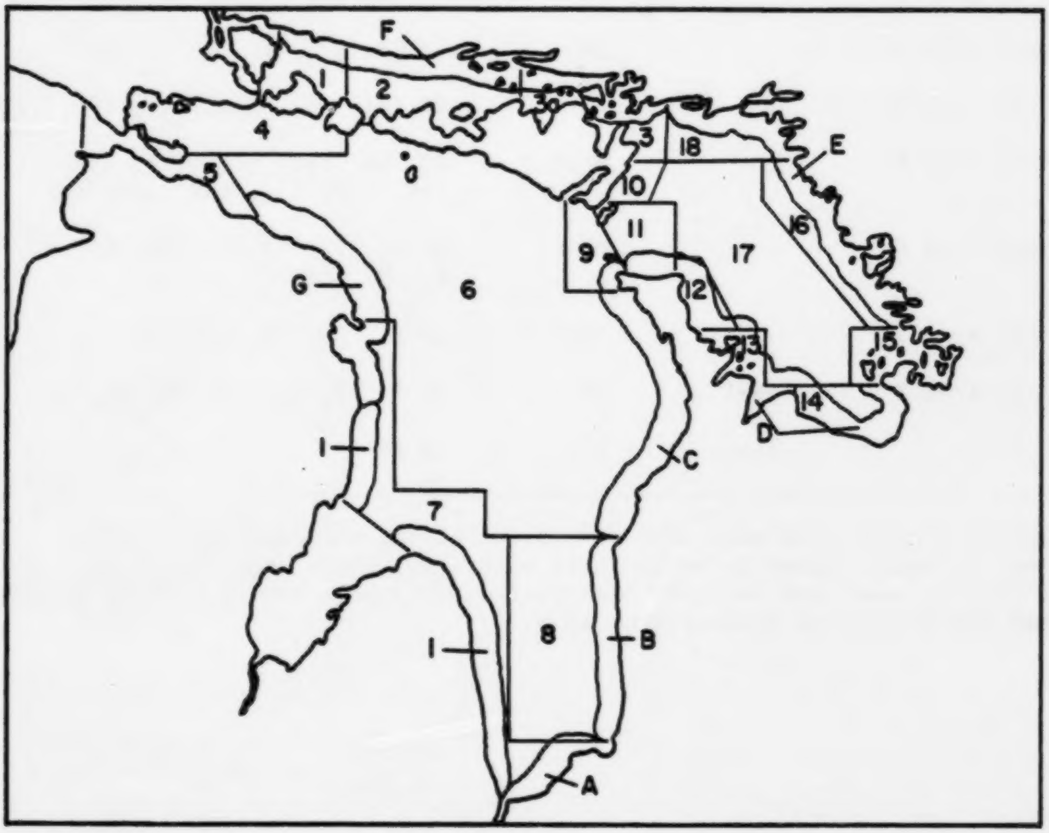
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Figure 5.1 Segmentation for Lake Huron, the North Channel, and Georgian Bay (from IJC 1976 and 1977).

Table 5.1. 1974 nearshore area acronyms, 1980 nearshore area acronyms, and 1980 monitoring sites assigned to area.

1974 Acronym	1980 Acronym	Maximum Depth	1980 Stations Assigned to Area
Nearshore Area A		17	LH 1, 3
Nearshore Area B		11	LH 4, 5, 10, 11
Nearshore Area C[1]		28	LH 28, 30, 41
Nearshore Area D		134	GB 101, 102, 103, 119, 131, 132
Nearshore Area E		56.5	GB 110, 115, 116, 123, 125, 126, 127, 138, 139, 141, 142
Nearshore Area F		46	LH 71, 72, 73, 74, 79, 81, 84, 85, 87, 88
Nearshore Area G		21.5	LH 34, 35, 36, 46, 47, 55
Nearshore Area I	NS-I	23	LH 7, 13, 14, 17, 23, 25, 94
River	river	13	LH 69

[1] Comparison of 1974 data with 1980 data required the exclusion of stations LH39 and 40 which appear to be included within nearshore area C of Figure 5-1. These stations were not included because they were more than 3 km from shore and had maximum depths greater than 15 m.

Table 5.2. 1974 open lake area acronyms, 1980 open lake area acronyms, and 1980 monitoring sites assigned to area.

1974 Acronym	1980 Acronym	1980 Maximum Depth	1980 Stations Assigned to Area
		North Channel	
Area 1	WNC	58	68, 70-72, 75-76
Area 2	CNC	76	73-74, 77-86
Area 3a	ENC	46	87-89
		Lake Huron	
Area 4	A4LH	68	60, 65-67
Area 5	A5LH	53.5	56, 62-64
Area 6[1]	NBLH	180	27, 29, 31-33, 37-38, 43-45 48, 51-54, 57, 61
Area 7[1]	SBM	62	16, 18-21, 24, 26
Area 8[1]	SBLH	87	6, 9, 12, 15, 90-93
Area 9		52	42, 49
		Georgian Bay	
Area 10		53	136
Area 11		134	130-135
Area 12		134	118-120
Area 13		96	101-102, 112
Area 14		86	103-104, 106
Area 15		66	105, 107-109
Area 16		56.5	110, 115-116, 123
Area 17	CBGB	95	111, 113-114, 117-118, 121-122, 124, 128-130, 137
Area 18		27	125-127, 138-139
Area 3		41	140-144

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[1] Stations 39-40 (Area 6), station 22 (Area 7), and station 8 (Area 8) are in depths greater than 15 m or more than 3 km from nearest shore but do not cluster with the associated areas.

scheme (Tables 5.1 and 5.2, Fig. 5.1). Ten of the nineteen segments from the 1974 scheme were selected to compare with the 1980 surveillance results (Tables 5.1 and 5.2). When epilimnetic and hypolimnetic chemical concentrations are presented for 1980 data in tables or graphs, epilimnetic refers to surface samples during unstratified periods and hypolimnetic refers to the lower layer during unstratified or isothermal periods. The lower layer is defined for each area and depends on the sample pattern. The epilimnion is approximated by taking all samples with a water temperature above a given temperature depending on the area and cruise involved. Similarly, the hypolimnion is approximated by taking all samples below another given temperature. These two temperatures were determined from the EBT temperature traces for all stations within an area for each cruise. S/E is used for surface/epilimnion data and L/H is used for lower layer/hypolimnion data.

Nine of the segments selected for comparison were open water areas. The tenth area is nearshore area I where Saginaw Bay was expected to affect Lake Huron. Five of the open water areas were in Lake Huron. The northern and central basins of Lake Huron (NBLH) were combined and represented the largest segment in the open waters of Lake Huron. It was least directly affected by external inputs such as tributaries, flow from the other water bodies, and anthropogenic activities. The southern basin of Lake Huron (SBLH) was the southernmost extension of Lake Huron and was the area most likely affected by Saginaw Bay inputs. This basin was principally affected by the addition of dissolved materials derived from the mixing of Saginaw Bay waters containing anthropogenic inputs (Schelske and Roth 1973) with the northern and central basin waters. Saginaw Bay mouth (SBM) was represented by stations placed near and outside of the bay mouth to monitor effects of the bay on Lake Huron.

The nearshore zone - I (NS-I) represented the western Saginaw Bay nearshore area (stations LH 23, 25) and eastern Saginaw Bay nearshore (stations LH 17, 94) and the western nearshore along southern Lake Huron (stations LH 7, 13, 14). This segment was chosen to represent nearshore areas and to focus on the impact of Saginaw Bay upon Lake Huron. Two northern basin segments, A4LH and A5LH, represented areas where Lake Superior and Lake Michigan waters intermix with Lake Huron water.

The central basin of Georgian Bay (CBGB) was the largest Georgian Bay segment, both in surface area and in volume. Because the boundaries were set more than 3 km from shore, it was anticipated to be the least affected by tributaries and interactions with other water bodies. This segment was considered representative of the chemistry and biology of Georgian Bay.

The North Channel was divided into three open lake segments corresponding to the 1974 scheme, west North Channel (WNC), central North Channel (CNC), and east North Channel (ENC) (Table 5.1). The data for all three segments have been included because of the high variability of this water body. There was a large east to west gradient in the water chemistry for many of the 1980 cruises. The chemical composition of the North Channel waters was primarily affected by the outflow from Lake Superior. The chemical gradients from west to east were very pronounced; and, as a consequence, no single area in the North Channel was representative of the area as a whole (Warry 1978a).

Northern Lake Huron waters were affected by the outflow of Lake Michigan through the Straits of Mackinaw and of Lake Superior through the St. Marys River. The northern areas of Lake Huron have concentrations of conservative elements which were approximately a mixture of 40% Lake Michigan and 60% Lake Superior water, the relative proportions of the two largest inputs to the northeastern part of the lake (Schelske and Roth 1973). An additional source was the dissolved materials input by Canadian and United States tributaries. Canadian tributaries pass through silica-rich granites and gneisses of the Canadian Shield and carbonate-rich limestones and shales of the St. Lawrence platform (Warry 1978b). United States tributaries pass through carbonates, dolomite, shale, sandstone, limestone, siltstone, and unconsolidated sediments consisting of sand and gravel beds in glacial drift and post-glacial alluvium (US Geological Survey 1975).

Results and Discussion

Phosphorus -- The three forms of phosphorus routinely measured during the surveillance program were total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP). From these analyses, particulate phosphorus and soluble organic phosphorus were computed. Annual mean total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) concentrations were higher in the L/H layer (Tables 5.3-5.24). In shallow water areas, vertical mixing minimized differences between the S/E and L/H layers. L/H concentrations were frequently greater in areas isolated from shore influences and in the open lake (Figs. 5.2-5.4). The greater concentration of TP in the L/H layer was probably due to algal utilization of phosphorus in the S/E layer and the subsequent settling of the particulate forms (Hutchinson 1957, Paerl et al. 1975). Thus, statistically significant TP, TDP, and SRP concentration differences between S/E and L/H layers were observed primarily during the stratified period in the open lake (see Chapter 4). Thermal stratification was completed by cruise 4 and continued through cruise 6.

Table 5.3. Nutrient and major ion concentrations in the epilimnion of North/Central Lake Huron (NBLH) during 1980 (stations 27, 29, 31-33, 37-38, 43-45, 48, 51-54, 57, 61).

Cruise No. Dates	1* 4/15-4/23	2* 5/11-5/16	3* 5/29-6/4	4 7/20-7/24	5 9/11-9/14	6 10/27-10/30	Cruise Annual Summary
Total Phosphorus (µg P/L)	5.1 [4.2-6.0] (11)	4.6 [4.2-5.0] (17)	4.4 [4.2-4.7] (17)	4.5 [4.1-4.8] (36)	4.4 [4.0-4.8] (30)	4.9 [4.6-5.2] (47)	4.7 [4.3-5.0] (6)
Total Diss. Phosphorus (µg P/L)	2.9 [2.0-3.9] (11)	2.3 [2.0-2.6] (17)	2.2 [2.1-2.4] (17)	2.2 [2.1-2.3] (36)	2.2 [2.0-2.3] (30)	2.3 [2.2-2.5] (47)	2.4 [2.1-2.6] (6)
Ortho Phosphorus (µg P/L)	0.93 [0.71-1.20] (15)	0.55 [0.44-0.65] (17)	0.80 [0.80-0.80] (17)	0.51 [0.36-0.65] (36)	0.66 [0.58-0.74] (30)	0.66 [0.61-0.70] (47)	0.69 [0.52-0.85] (6)
Diss. Nitrate + Nitrite (µg N/L)	296 [289-303] (15)	283 [277-289] (17)	298 [295-301] (17)	257 [254-260] (36)	238 [233-242] (30)	288 [284-292] (47)	277 [252-302] (6)
Dissolved Ammonia (µg N/L)	1.9 [1.4-2.4] (15)	1.7 [1.4-2.1] (17)	2.1 [1.4-2.7] (17)	1.7 [1.3-2.0] (36)	1.4 [0.99-1.7] (30)	2.2 [1.8-2.6] (47)	1.8 [1.5-2.1] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.55 [1.51-1.60] (15)	1.52 [1.49-1.54] (17)	1.50 [1.49-1.50] (17)	1.19 [1.15-1.23] (36)	0.90 [0.88-0.90] (30)	1.33 [1.29-1.37] (47)	1.33 [1.07-1.59] (6)
Dissolved Oxygen (mg/L)	13.8 [13.1-14.5] (3)	13.7 [12.4-14.9] (3)	13.6 [13.6-13.7] (17)	— — (0)	10.4 [10.2-10.6] (30)	11.7 [11.5-11.8] (47)	12.6 [10.7-14.5] (5)
pH	8.08 [7.99-8.17] (15)	7.99 [7.88-8.10] (17)	8.30 [8.25-8.35] (17)	8.23 [8.20-8.25] (36)	8.34 [8.30-8.37] (30)	8.17 [8.10-8.23] (47)	8.19 [8.05-8.32] (6)
Specific Conductance (µmho/cm)	203.4 [201.4-205.4] (15)	202.6 [201.5-203.6] (17)	202.6 [199.1-206.1] (17)	196.0 [191.2-200.8] (36)	191.6 [189.6-193.7] (39)	207.8 [205.8-209.9] (17)	200.7 [194.2-207.1] (6)
Chloride (mg/L)		5.4 [5.4-5.4] (17)	5.5 [5.4-5.6] (17)	5.2 [5.0-5.5] (21)	5.3 [5.2-5.4] (30)	5.5 [5.4-5.6] (17)	5.4 [5.2-5.5] (5)
Sulfate (mg/L)		15.4 [15.2-15.6] (17)	15.6 [15.4-15.8] (17)	14.8 [14.1-15.4] (21)	15.2 [15.0-15.4] (30)	15.7 [15.6-15.8] (17)	15.3 [14.9-15.8] (5)
Alkalinity (mg $CaCO_3$/L)	76.9 [76.2-77.6] (15)	76.6 [75.9-77.3] (17)	79.0 [77.9-80.0] (17)	75.0 [72.6-77.4] (36)	77.2 [76.1-78.2] (30)	78.4 [77.8-79.0] (17)	77.2 [75.7-78.7] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

Table 5.4. Nutrient and major ion concentrations in the hypolimnion of north central Lake Huron (NBLH) during 1980 (stations 27, 29, 31-33, 37-38, 43,-45, 48, 51-54, 57, 61).

Cruise No. Dates	1* 4/15-4/23	2* 5/11-5/16	3* 5/29-6/4	4 7/20-7/24	5 9/11-9/14	6 10/27-10/30	Cruise Annual Summary
Total Phosphorus (µg P/L)	7.9 [1.6-14.1] (18)	4.6 [4.3-4.8] (15)	6.3 [3.9-8.7] (15)	5.6 [5.3-5.9] (45)	5.1 [4.7-5.4] (48)	5.3 [4.9-5.7] (24)	5.8 [4.6-7.0] (6)
Total Diss. Phosphorus (µg P/L)	2.8 [2.0-3.6] (18)	2.1 [1.8-2.4] (15)	2.0 [2.0-2.1] (15)	2.9 [2.7-3.1] (45)	2.5 [2.3-2.7] (48)	3.0 [2.8-3.2] (23)	2.6 [2.1-3.0] (6)
Ortho Phosphorus (µg P/L)	1.30 [0.85-1.70] (12)	0.61 [0.48-0.73] (15)	0.80 [0.80-0.80] (15)	0.82 [0.63-1.01] (46)	1.20 [1.10-1.40] (48)	1.70 [1.50-1.90] (24)	1.10 [0.65-1.50] (6)
Diss. Nitrate + Nitrite (µg N/L)	289 [277-302] (12)	283 [279-287] (15)	301 [299-304] (15)	296 [292-300] (45)	320 [314-326] (48)	331 [329-332] (24)	303 [283-323] (6)
Dissolved Ammonia (µg N/L)	2.1 [1.0-3.1] (12)	1.6 [1.3-1.9] (15)	2.4 [1.8-3.0] (15)	6.2 [5.2-7.2] (45)	1.2 [0.95-1.4] (48)	1.5 [1.3-1.8] (24)	2.5 [0.54-4.5] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.71 [1.59-1.83] (12)	1.56 [1.54-1.58] (15)	1.50 [1.50-1.50] (15)	1.71 [1.62-1.79] (45)	1.74 [1.64-1.85] (48)	1.85 [1.80-1.90] (24)	1.68 [1.54-1.81] (6)
Dissolved Oxygen (mg/L)	13.1 [12.1-14.1] (7)	13.7 [12.4-14.9] (3)	13.6 [13.5-13.7] (15)	12.5 [12.3-12.7] (15)	12.5 [12.3-12.7] (48)	12.6 [12.5-12.7] (24)	13.0 [12.4-13.6] (6)
pH	8.00 [7.92-8.08] (12)	7.98 [7.95-8.02] (1)	8.24 [8.20-8.29] (15)	7.87 [7.84-7.90] (46)	8.06 [8.03-8.09] (48)	7.97 [7.86-8.08] (24)	8.03 [7.88-8.15] (6)
Specific Conductance (µmho/cm)	202.6 [200.0-205.3] (12)	201.8 [200.6-203.2] (15)	205.0 [201.4-208.6] (15)	203.2 [202.5-204.0] (46)	197.6 [196.2-198.8] (48)	211.4 [210.8-212.0] (24)	203.6 [198.8-208.4] (6)
Chloride (mg/L)		5.4 [5.3-5.4] (15)	5.4 [5.4-5.5] (15)	5.4 [5.4-5.5] (27)	5.5 [5.4-5.5] (48)	5.5 [5.4-5.6] (24)	5.4 [5.4-5.5] (5)
Sulfate (mg/L)		15.4 [15.1-15.6] (15)	15.4 [15.1-15.6] (15)	15.3 [15.2-15.4] (27)	15.5 [15.4-15.6] (48)	15.7 [15.6-15.8] (24)	15.5 [15.2-15.7] (5)
Alkalinity (mg $CaCO_3$/L)	77.2 [76.4-77.9] (12)	76.4 [75.5-77.2] (15)	79.7 [79.0-80.4] (15)	79.5 [79.2-79.8] (46)	79.2 [78.4-80.0] (48)	79.4 [78.8-79.8] (24)	78.6 [77.1-80.0] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - hypolimnion represented by samples with depth greater than 100 m.

Table 5.5. Nutrient and major ion concentrations in the epilimnion of central basin of Georgian Bay (CBGB) during 1980 (stations 111, 113-114, 117-118, 121-122, 124, 128-130, 137).

Cruise No. Dates	1* 4/24-26/80	2** 5/19-5/21	3 6/6-6/7	4 7/27-7/30	5 9/19-9/21	6 11/2-11/4	Cruise Annual Summary
Total Phosphorus (μg P/L)	4.4 [4.0-4.8] (12)	4.7 [4.1-5.3] (13)	4.8 [4.1-5.4] (10)	3.5 [3.1-3.9] (23)	3.5 [3.3-3.7] (19)	4.2 [3.9-4.5] (17)	4.2 [3.6-4.8] (6)
Total Diss. Phosphorus (μg P/L)	2.3 [2.1-2.5] (10)	2.3 [1.9-2.7] (11)	2.0 [1.7-2.4] (12)	1.9 [1.8-2.1] (23)	2.0 [1.8-2.2] (19)	2.2 [1.9-2.5] (17)	2.1 [1.9-2.3] (6)
Ortho Phosphorus (μg P/L)	0.69 [0.53-0.85] (12)	0.42 [0.32-0.51] (13)	0.71 [0.57-0.85] (10)	0.27 [0.17-0.36] (23)	0.63 [0.51-0.74] (19)	0.36 [0.32-.40] (17)	0.51 [0.32-0.71] (6)
Diss. Nitrate + Nitrite (μg N/L)	277 [273-281] (12)	276 [272-280] (13)	265 [261-268] (10)	238 [233-243] (23)	232 [230-233] (19)	269 [266-273] (17)	259.5 [238.9-280.1] (6)
Dissolved Ammonia (μg N/L)	2.1 [1.9-2.3] (12)	1.8 [1.3-2.2] (13)	1.6 [0.2-3.0] (10)	2.0 [1.8-2.2] (23)	1.0 [1.0-1.0] (19)	1.8 [1.5-2.0] (17)	1.7 [1.3-2.1] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.23 [1.20-1.26] (12)	1.23 [1.17-1.28] (13)	1.18 [1.13-1.24] (13)	0.92 [0.90-0.94] (23)	0.85 [0.83-0.86] (19)	1.16 [1.13-1.18] (17)	1.10 [0.92-1.27] (6)
Dissolved Oxygen (mg/L)	— — (0)	— — (0)	12.5 [12.3-12.7] (10)	— — (0)	10.1 [10.0-10.2] (19)	11.6 [11.4-11.7] (17)	11.4 [8.4-14.4] (3)
pH	8.01 [7.97-8.05] (12)	7.94 [7.89-7.98] (13)	8.09 [8.04-8.14] (10)	8.15 [8.11-8.19] (23)	8.23 [8.16-8.30] (19)	8.03 [8.01-8.06] (17)	8.08 [7.97-8.18] (6)
Specific Conductance (μmho/cm)	190.6 [190.3-190.9] (12)	185.7 [179.7-191.7] (13)	185.6 [181.2-190.0] (10)	184.4 [183.3-185.5] (23)	178.8 [177.5-180.1] (19)	193.7 [191.9-195.6] (17)	186.5 [181.0-191.9] (6)
Chloride (mg/L)		4.8 [4.7-5.0] (6)	4.9 [4.7-5.1] (10)	4.7 [4.6-4.8] (14)	4.9 [4.8-5.0] (19)	5.0 [5.0-5.1] (17)	4.9 [4.7-5.0] (5)
Sulfate (mg/L)		15.4 [15.1-15.7] (6)	15.6 [15.0-16.1] (10)	14.8 [14.6-15.0] (23)	15.2 [15.1-15.2] (19)	15.5 [15.4-15.6] (17)	15.3 [14.9-15.7] (5)
Alkalinity (mg $CaCO_3$/L)	70.5 [70.2-70.8] (12)	70.8 [67.6-74.0] (13)	72.0 [69.8-74.2] (10)	69.5 [68.9-70.0] (23)	71.8 [71.1-72.5] (19)	72.1 [71.3-72.9] (17)	71.1 [70.0-72.2] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

**Unstratified conditions - epilimnion represented by upper 10-m layer.

Table 5.6. Nutrient and major ion concentrations in the hypolimnion of central basin of Georgian Bay (CBGB) during 1980 (stations 111, 113-114, 117-118, 121-122, 124, 128-130, 137).

Cruise No. Dates	1* 4/24-26/80	2** 5/19-5/21	3 6/6-6/7	4 7/27-7/30	5 9/19-9/21	6 11/2-11/4	Cruise Annual Summary
Total Phosphorus (µg P/L)	5.3 [3.5-7.0] (11)	4.0 [3.7-4.3] (12)	3.9 [3.8-4.1] (36)	4.9 [4.5-5.3] (36)	4.1 [3.8-4.3] (23)	4.6 [0.0-10.3] (2)	4.6 [3.8-5.3] (6)
Total Diss. Phosphorus (µg P/L)	2.7 [2.1-3.3] (11)	2.0 [1.8-2.3] (12)	1.8 [1.7-1.9] (36)	2.1 [2.0-2.2] (36)	2.0 [1.9-2.1] (23)	2.6 [1.9-3.2] (2)	2.2 [1.8-2.6] (6)
Ortho Phosphorus (µg P/L)	1.13 [0.47-1.78] (11)	0.56 [0.46-0.65] (12)	0.71 [0.63-0.80] (36)	0.40 [0.32-0.49] (36)	0.90 [0.82-0.97] (23)	0.45 [0.00-1.10] (2)	0.69 [0.40-0.99] (6)
Diss. Nitrate + Nitrite (µg N/L)	276 [273-280] (11)	279 [277-280] (12)	276 [275-277] (36)	264 [256-271] (36)	289 [285-293] (23)	305 [305-305] (2)	282 [267-296] (6)
Dissolved Ammonia (µg N/L)	3.2 [2.0-4.4] (11)	1.9 [1.7-2.1] (12)	1.7 [1.1-2.2] (36)	6.6 [5.4-7.7] (36)	1.0 [1.0-1.0] (23)	2.0 [0.0-14.7] (2)	2.7 [0.61-4.9] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.24 [1.22-1.26] (11)	1.18 [1.16-1.19] (12)	1.19 [1.16-1.22] (36)	1.27 [1.19-1.35] (36)	1.34 [1.28-1.39] (23)	1.50 [1.37-1.63] (2)	1.29 [1.16-1.41] (6)
Dissolved Oxygen (mg/L)	14.3 [14.1-14.5] (6)	13.5 [13.3-3.8] (7)	13.4 [13.4-13.5] (36)	12.2 [11.8-12.5] (12)	12.4 [12.2-12.6] (23)	12.2 [12.2-12.2] (2)	13.0 [12.1-13.9] (6)
pH	8.03 [7.98-8.09] (11)	7.92 [7.87-7.95] (11)	8.10 [8.08-8.12] (36)	7.85 [7.79-7.91] (36)	8.13 [8.08-8.18] (23)	7.90 [7.57-8.21] (2)	7.99 [7.88-8.11] (6)
Specific Conductance (µmho/cm)	190.9 [190.6-191.3] (11)	190.0 [189.7-190.3] (12)	190.8 [190.2-191.3] (36)	188.6 [187.9-189.3] (36)	184.5 [182.1-186.9] (23)	194.0 [194.0-194.0] (2)	189.8 [186.5-193.1] (6)
Chloride (mg/L)		4.9 [4.8-5.0] (10)	4.9 [4.9-5.0] (36)	4.8 [4.7-4.9] (20)	4.9 [4.9-5.0] (23)	5.0 [4.4-5.7] (2)	4.9 [4.8-5.0] (5)
Sulfate (mg/L)		15.5 [15.4-15.7] (19)	15.5 [15.4-15.6] (36)	15.0 [14.8-15.2] (20)	15.3 [15.2-15.5] (23)	15.8 [12.6-18.9] (2)	15.4 [15.1-15.8] (5)
Alkalinity (mg $CaCO_3$/L)	70.6 [70.2-71.0] (11)	73.4 [72.9-73.8] (12)	74.5 [73.8-75.2] (36)	72.3 [71.8-72.8] (36)	72.9 [72.3-73.4] (23)	73.0 [73.0-73.0] (2)	72.8 [71.4-74.1] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 53 m.

**Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 52.5 m.

Table 5.7. Nutrient and major ion concentrations in the epilimnion of west North Channel (WNC) during 1980 (stations 58, 70-72, 75-76).

Cruise No. Dates	1* 4/20-4/21	2* 5/16	3 6/4	4 7/25-7/26	5 9/15	6** 10/31-11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	8.2 [5.7-10.6] (9)	6.0 [5.2-6.9] (8)	4.8 [4.4-5.2] (7)	6.4 [5.6-7.1] (12)	5.8 [4.9-5.5] (13)	6.9 [5.0-8.7] (7)	6.4 [5.1-7.6] (6)
Total Diss. Phosphorus (µg P/L)	4.1 [3.2-5.0] (9)	2.3 [2.1-2.5] (8)	1.9 [1.8-2.0] (7)	2.9 [2.5-3.3] (12)	2.1 [2.0-2.3] (13)	2.3 [1.7-2.9] (7)	2.6 [1.8-3.4] (6)
Ortho Phosphorus (µg P/L)	1.3 [0.79-1.9] (9)	0.62 [0.54-0.71] (8)	0.63 [0.42-0.84] (7)	0.41 [0.35-0.47] (12)	0.79 [0.71-0.88] (13)	0.69 [0.48-0.89] (7)	0.74 [0.42-1.06] (6)
Diss. Nitrate + Nitrite (µg N/L)	290 [275-306] (9)	287 [284-291] (8)	265 [255-275] (7)	237 [227-248] (12)	275 [269-280] (13)	290 [285-295] (7)	274 [252-296] (6)
Dissolved Ammonia (µg N/L)	11.8 [1.8-21.7] (9)	5.9 [0.8-11.0] (8)	3.4 [0.3-6.6] (7)	3.4 [2.8-4.0] (12)	1.0 [1.0-1.0] (13)	2.6 [0.5-4.6] (7)	4.7 [0.7-8.7] (6)
Diss. Reactive Silica (mg SiO_2/L)	2.10 [1.95-2.26] (9)	2.05 [1.92-2.19] (8)	1.98 [1.96-1.99] (7)	1.70 [1.57-1.84] (12)	1.70 [1.59-1.81] (13)	1.73 [1.61-1.84] (7)	1.88 [1.68-2.07] (6)
Dissolved Oxygen (mg/L)	14.0 [11.5-16.5] (2)	12.3 [12.3-12.3] (2)	11.3 [11.0-11.6] (7)	-- -- (0)	10.2 [10.2-10.3] (13)	11.9 [11.6-12.2] (7)	11.9 [10.2-13.7] (5)
pH	7.78 [7.70-7.86] (9)	7.77 [7.64-7.90] (8)	8.27 [8.20-8.35] (7)	7.97 [7.94-8.00] (12)	8.02 [7.99-8.06] (13)	8.10 [7.97-8.23] (7)	7.99 [7.78-8.19] (6)
Specific Conductance (µmho/cm)	129.2 [109.2-149.3] (9)	131.2 [109.9-152.6] (8)	125.9 [108.3-143.4] (7)	134.8 [124.2-145.5] (12)	156.7 [154.8-158.6] (13)	172.4 [149.7-195.1] (7)	141.7 [122.2-161.2] (6)
Chloride (mg/L)	—	2.9 [2.0-3.8] (8)	2.6 [1.9-3.3] (7)	2.9 [2.2-3.6] (12)	4.0 [3.8-4.1] (13)	4.1 [3.3-5.0] (7)	3.3 [2.4-4.2] (5)
Sulfate (mg/L)	—	8.0 [4.6-11.4] (7)	7.5 [5.0-9.9] (7)	8.4 [6.2-10.5] (12)	11.9 [11.3-12.4] (13)	12.5 [10.4-14.7] (7)	9.7 [6.7-12.6] (5)
Alkalinity (mg $CaCO_3$/L)	50.8 [44.0-57.5] (9)	51.0 [43.6-58.4] (8)	52.1 [47.5-56.8] (7)	54.5 [51.4-57.4] (12)	60.8 [60.2-61.4] (13)	67.0 [58.7-75.3] (7)	56.0 [49.2-62.9] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper 10 m.

**Isothermal conditions - epilimnion represented by surface samples which were the only samples in the upper 10 m.

Table 5.8. Nutrient and major ion concentrations in the hypolimnion of west North Channel (WNC) during 1980 (stations 68, 70-72, 75-76).

Cruise No. Dates	1* 4/20-4/21	2** 5/16	3 6/4	4 7/25-7/26	5 9/15	6$^+$ 10/31-11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	6.2 [3.1-9.3] (7)	5.2 [4.4-6.1] (7)	4.8 [4.4-5.1] (10)	6.4 [5.5-7.3] (13)	5.3 [4.5-6.1] (5)	5.9 [4.1-7.6] (5)	5.6 [4.9-6.3] (6)
Total Diss. Phosphorus (µg P/L)	3.4 [2.3-4.5] (7)	2.2 [1.9-2.5] (7)	2.1 [1.9-2.4] (10)	2.9 [2.7-3.1] (13)	2.0 [1.8-2.3] (5)	2.3 [1.7-2.9] (5)	2.5 [1.9-3.1] (6)
Ortho Phosphorus (µg P/L)	1.1 [0.47-1.8] (7)	0.59 [0.50-0.67] (7)	0.82 [0.63-1.0] (10)	0.43 [0.29-0.58] (13)	0.80 [0.65-0.95] (5)	0.50 [0.41-0.59] (5)	0.71 [0.45-0.98] (6)
Diss. Nitrate + Nitrite (µg N/L)	296 [279-314] (7)	290 [287-294] (7)	304 [299-309] (10)	293 [287-399] (13)	310 [302-317] (5)	292 [286-298] (5)	298 [289-306] (6)
Dissolved Ammonia (µg N/L	12.0 [0.0-26.4] (7)	3.7 [1.5-5.9] (7)	4.1 [2.8-5.4] (10)	7.8 [6.2-9.5] (13)	1.0 [1.0-1.0] (5)	3.8 [0.8-6.8] (5)	5.4 [1.3-9.5] (6)
Diss. Reactive Silica (mg SiO_2/L)	2.07 [1.79-2.35] (7)	1.94 [1.79-2.08] (7)	2.00 [1.95-2.05] (10)	1.92 [1.81-2.03] (13)	1.76 [1.72-1.79] (5)	1.66 [1.51-1.81] (5)	1.89 [1.73-2.05] (6)
Dissolved Oxygen (mg/L)	13.8 [13.6-14.1] (4)	13.2 [12.4-13.9] (4)	12.9 [12.7-13.1] (10)	11.5 [10.7-12.3] (6)	10.9 [10.7-11.1] (5)	11.6 [11.4-11.8] (5)	12.3 [11.1-13.5] (6)
pH	7.78 [7.67-7.88] (7)	7.92 [7.82-8.01] (7)	8.19 [8.14-8.24] (10)	7.70 [7.63-7.77] (13)	7.98 [7.96-8.00] (15)	7.97 [7.92-8.01] (5)	7.93 [7.73-8.10] (6)
Specific Conductance (µmho/cm)	149.7 [124.8-174.6] (7)	159.3 [143.6-175.0] (7)	167.2 [159.4-175.0] (10)	176.3 [167.8-184.9] (13)	175.6 [168.3-182.9] (5)	178.0 [151.2-204.9] (5)	167.7 [155.8-179.5] (6)
Chloride (mg/L)		4.0 [3.40-4.60] (7)	4.0 [3.70-4.30] (10)	4.5 [4.30-4.70] (13)	4.8 [4.60-5.00] (5)	4.4 [3.40-5.50] (5)	4.3 [3.91-4.77] (5)
Sulfate (mg/L)		11.7 [9.80-13.6] (7)	12.1 [11.2-12.9] (10)	13.0 [12.6-13.4] (13)	14.0 [13.6-14.5] (5)	13.1 [9.90-16.3] (5)	12.8 [11.7-13.9] (5)
Alkalinity (mg$CaCO_3$/L)	57.4 [48.8-66.0] (7)	61.7 [56.00-67.5] (7)	63.7 [61.2-66.2] (10)	68.5 [64.8-72.2] (13)	69.4 [65.8-73.0] (5)	66.6 [58.9-74.3] (5)	64.6 [59.8-69.3] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.
*Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 27 m.
**Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 29 m.
+Isothermal conditions - hypolimnion represented by samples with depth equal to or greater than 32 m.

Table 5.9. Nutrient and major ion concentrations in the epilimnion of center North Channel (CNC) during 1980 (stations 73-73, 77-86).

Cruise No. Dates	1* 4/21	2* 5/16-5/17	3 6/5	4 7/26	5 9/15	6** 10/31-11/1	Cruise Annual Summary
Total Phosphorus (μg P/L)	4.8 [4.8-4.8] (1)	5.6 [4.7-6.6] (14)	5.1 [4.6-5.7] (20)	4.2 [4.0-4.5] (25)	4.5 [4.3-4.7] (23)	6.0 [5.3-6.8] (13)	5.0 [4.3-5.7] (6)
Total Diss. Phosphorus (μg P/L)	2.6 [2.6-2.6] (1)	2.5 [2.3-2.7] (14)	2.2 [2.0-2.3] (20)	2.2 [2.1-2.3] (25)	2.2 [2.0-2.3] (22)	2.2 [2.1-2.3] (12)	2.3 [2.1-2.5] (6)
Ortho Phosphorus (μg P/L)	0.82 [0.55-1.09] (3)	0.81 [0.59-1.04] (14)	0.66 [0.58-0.74] (20)	0.38 [0.29-0.46] (23)	0.83 [0.73-0.94] (23)	0.54 [0.49-0.58] (13)	0.67 [0.48-0.87] (6)
Diss. Nitrate + Nitrite (μg N/L)	299 [296-303] (5)	295 [276-314] (14)	284 [274-294] (20)	254 [252-256] (25)	257 [251-262] (23)	280 [278-285] (13)	278 [258-298] (6)
Dissolved Ammonia (μg N/L)	1.8 [0.8-2.8] (5)	7.2 [1.6-12.9] (14)	5.9 [1.6-10.3] (20)	3.6 [3.1-4.1] (25)	1.0 [1.0-1.0] (23)	2.7 [2.2-3.2] (13)	3.7 [1.2-6.2] (6)
Diss. Reactive Silica (mg SiO_2/L)	2.04 [1.78-2.31] (5)	2.11 [1.97-2.25] (14)	2.05 [1.94-2.16] (20)	1.60 [1.57-1.63] (25)	1.49 [1.44-1.53] (23)	1.75 [1.69-1.82] (13)	1.84 [1.56-2.12] (6)
Dissolved Oxygen (mg/L)	— — (0)	13.2 [10.7-15.7] (2)	11.9 [11.7-12.1] (20)	— — (0)	9.9 [9.7-10.1] (230	11.7 [11.5-11.9] (13)	11.7 [9.5-13.8] (4)
pH	7.85 [7.81-7.89] (5)	7.85 [7.78-7.91] (14)	8.26 [8.23-8.29] (20)	8.10 [8.07-8.13] (25)	8.09 [8.04-8.14] (23)	8.08 [7.99-8.16] (13)	8.04 [7.87-8.21] (6)
Specific Conductance (μmho/cm)	168.8 [161.4-176.2] (5)	158.6 [153.9-163.3] (14)	160.5 [155.0-165.9] (20)	155.4 [153.7-157.1] (25)	160.1 [157.7-162.5] (23)	174.8 [168.6-180.9] (13)	163.0 [155.4-170.7] (6)
Chloride (mg/L)		4.3 [4.1-4.5] (14)	4.4 [4.3-4.5] (20)	4.1 [4.0-4.3] (15)	4.4 [4.4-4.5] (23)	4.4 [4.1-4.7] (13)	4.3 [4.2-4.5] (5)
Sulfate (mg/L)		13.8 [12.8-14.8] (14)	14.7 [14.2-15.3] (20)	13.3 [12.7-13.9] (15)	14.0 [13.7-14.3] (23)	13.8 [12.8-14.7] (13)	13.9 [13.3-14.5] (5)
Alkalinity (mg $CaCO_3$/L)	63.0 [60.0-66.0] (5)	58.8 [55.7-61.9] (14)	57.8 [54.2-61.4] (20)	57.1 [56.7-57.5] (25)	61.1 [59.9-62.4] (23)	63.6 [62.3-64.9] (13)	60.2 [57.4-63.1] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.
*Unstratified conditions - epilimnion represented by upper 10-m layer.
**Isothermal conditions - epilimnion represented by upper 10-m layer.

Table 5.10. Nutrient and major ion concentrations in the hypolimnion of center North Channel (CNC) during 1980 (stations 73-74, -7-86).

Cruise No. Dates	1* 4/21	2** 5/16-5/17	3 6/5	4 7/26	5 9/15	6*** 10/31-11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	4.3 [3.4-5.2] (3)	5.9 [4.4-7.4] (9)	4.7 [3.9-5.4] (18)	5.6 [5.0-6.2] (14)	5.4 [4.6-6.1] (4)	5.3 [5.1-5.6] (8)	5.2 [4.6-5.8] (6)
Total Diss. Phosphorus (µg P/L)	3.1 [2.1-4.0] (3)	3.1 [2.2-4.0] (9)	2.1 [2.0-2.1] (18)	2.3 [2.2-2.4] (14)	2.1 [1.7-2.4] (4)	2.2 [2.1-2.2] (8)	2.5 [2.0-3.0] (6)
Ortho Phosphorus (µg P/L)	0.70 [0.40-1.00] (5)	0.84 [0.46-1.2] (9)	0.71 [0.65-0.77] (18)	0.42 [0.28-0.57] (14)	0.98 [0.77-1.2] (4)	0.51 [0.43-0.59] (8)	0.70 [0.48-0.91] (6)
Diss. Nitrate + Nitrite (µg N/L)	298 [293-302] (5)	291 [286-296] (9)	306 [303-308] (18)	305 [296-315] (14)	317 [314-321] (4)	288 [276-300] (8)	301 [290-312] (6)
Dissolved Ammonia (µg N/L)	1.2 [0.6-1.8] (6)	7.9 [0.1-15.7] (9)	6.6 [4.5-8.7] (18)	4.9 [3.7-6.2] (14)	1.0 [1.0-1.0] (4)	2.6 [2.0-3.2] (8)	4.0 [1.0-7.1] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.82 [1.44-2.19] (5)	2.11 [1.92-2.31] (9)	2.04 [1.96-2.12] (18)	2.05 [1.83-2.28] (14)	1.65 [1.58-1.71] (4)	1.71 [1.62-1.79] (8)	1.90 [1.69-2.10] (6)
Dissolved Oxygen (mg/L)	13.5 [12.4-14.7] (3)	13.3 [13.0-13.5] (6)	12.9 [12.8-12.9] (18)	11.0 [10.5-11.5] (8)	11.9 [10.9-12.9] (4)	11.8 [11.7-12.0] (8)	12.4 [11.4-13.4] (6)
pH	7.90 [7.83-7.96] (5)	7.89 [7.85-7.83] (9)	8.17 [8.14-8.21] (18)	7.68 [7.58-7.79] (14)	8.07 [7.93-8.21] (4)	7.94 [7.86-8.02] (8)	7.94 [7.77-8.12] (6)
Specific Conductance (µmho/cm)	176.2 [163.2-189.2] (5)	165.8 [160.6-170.9] (9)	173.8 [170.2-177.4] (18)	175.9 [166.5-185.2] (14)	194.8 [192.0-197.5] (4)	184.2 [177.3-191.2] (8)	178.5 [168.0-188.9] (6)
Chloride (mg/L)		4.6 [4.4-4.8] (9)	4.6 [4.4-4.7] (18)	4.9 [4.5-5.3] (9)	5.5 [5.4-5.6] (4)	4.8 [4.6-4.9] (8)	4.9 [4.4-5.3] (5)
Sulfate (mg/L)		14.4 [14.0-14.9] (9)	14.3 [13.9-14.6] (18)	14.3 [14.1-14.6] (9)	15.3 [15.0-15.6] (4)	14.6 [14.2-14.9] (8)	14.6 [14.1-15.1] (5)
Alkalinity (mg $CaCO_3$/L)	66.6 [60.9-72.3] (5)	61.2 [58.5-63.9] (9)	64.0 [61.8-66.2] (18)	66.7 [62.0-71.4] (14)	77.3 [75.7-78.8] (4)	66.5 [62.8-70.2] (8)	67.0 [61.3-72.8] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 10 m.

**Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 30 m.

***Isothermal conditions - hypolimnion represented by samples with depth equal to or greater than 31 m.

Table 5.11. Nutrient and major ion concentrations in the epilimnion of east North Channel (ENC) during 1980 (stations 87-89).

Cruise No. Dates	1 4/21	2* 5/17	3 6/5	4 7/26-7/27	5** 9/16	6*** 11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	ICE COVERED---- NO SAMPLES	6.3 [2.4-10.2] (3)	4.9 [3.9-5.9] (6)	4.7 [3.4-5.9] (6)	5.2 [3.7-6.8] (3)	5.3 [4.2-6.4] (3)	5.3 [4.5-6.0] (5)
Total Diss. Phosphorus (µg P/L)		2.9 [1.2-4.8] (3)	2.0 [1.9-2.1] (6)	2.5 [2.2-2.8] (6)	1.6 [0.0-5.0] (3)	2.5 [2.4-2.7] (3)	2.3 [1.7-2.9] (5)
Ortho Phosphorus (µg P/L)		0.80 [0.80-0.80] (3)	0.63 [0.52-0.74] (6)	0.80 [0.00-2.0] (5)	1.0 [0.89-1.2] (3)	0.60 [0.35-0.85] (3)	0.77 [0.57-0.97] (5)
Diss. Nitrate + Nitrite (µg N/L)		229 [200-258] (3)	211 [204-219] (6)	220 [198-242] (6)	212 [167-257] (3)	234 [229-240] (3)	221 [209-234] (5)
Dissolved Ammonia (µg N/L)		1.7 [0.2-3.1] (3)	1.5 [0.9-2.1] (6)	4.7 [4.1-5.2] (6)	2.3 [0.0-5.2] (3)	3.7 [2.2-5.1] (3)	2.8 [1.1-4.5] (5)
Diss. Reactive Silica (mg SiO_2/L)		1.78 [1.40-2.17] (3)	1.52 [1.47-1.58] (6)	1.43 [1.33-1.53] (6)	1.56 [1.49-1.63] (3)	1.94 [1.91-1.98] (3)	1.65 [1.39-1.91] (5)
Dissolved Oxygen (mg/L)		— -- (0)	11.9 [11.8-12.1] (6)	— -- (0)	9.4 [9.2-9.7] (3)	11.3 [11.0-11.6] (3)	10.9 [7.6-14.1] (3)
pH		7.98 [7.89-8.07] (3)	8.33 [8.30-8.39] (6)	8.13 [8.09-8.17] (6)	8.10 [7.82-8.38] (3)	8.13 [8.05-8.22] (3)	8.13 [7.96-8.29] (5)
Specific Conductance (µmho/cm)		164.0 [155.0-173.0] (3)	168.7 [166.2-171.1] (6)	161.7 [159.8-163.5] (6)	157.7 [156.2-159.1] (3)	175.7 [150.8-200.6] (3)	165.6 [157.0-174.2] (5)
Chloride (mg/L)		4.4 [4.1-4.8] (3)	4.4 [4.3-4.5] (6)	4.1 [3.6-4.6] (6)	4.5 [4.1-4.9] (3)	4.4 [4.4-4.4] (9)	4.4 [4.2-4.5] (5)
Sulfate (mg/L)		14.9 [13.5-16.3] (3)	14.8 [14.7-14.9] (6)	13.8 [12.6-14.9] (6)	14.2 [13.0-15.5] (3)	14.9 [14.6-15.2] (9)	14.5 [13.9-15.1] (5)
Alkalinity (mg $CaCO_3$/L)		60.3 [54.6-66.1] (3)	60.3 [59.5-61.2] (6)	59.5 [58.6-60.4] (6)	59.0 [59.0-59.0] (3)	60.3 [58.9-61.8] (3)	59.9 [59.1-60.6] (5)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper 10 m.

**Almost isothermal conditions - epilimnion represented by surface samples which were the only samples in the upper 10 m.

***Isothermal conditions - epilimnion represented by surface samples which were the only samples in the upper 10 m.

Table 5.12. Nutrient and major ion concentrations in the hypolimnion of east North Channel (ENC) during 1980 (stations 87-89).

Cruise No. Dates	1* 4/21	2 5/17	3 6/5	4 7/26-7/27	5** 9/16	6+ 11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	ICE COVERED---- NO SAMPLES	5.5 [4.1-6.8] (4)	5.0 [4.6-5.4] (7)	5.1 [4.7-5.6] (6)	5.1 [4.9-5.4] (6)	5.4 [5.1-5.8] (3)	5.2 [5.0-5.5] (5)
Total Diss. Phosphorus (µg P/L)		2.4 [2.2-2.5] (4)	2.1 [2.1-2.2] (7)	2.4 [2.3-2.6] (6)	2.4 [2.2-2.7] (6)	2.9 [1.3-4.4] (3)	2.4 [2.1-2.8] (5)
Ortho Phosphorus (µg P/L)		0.75 [0.47-1.0] (4)	0.60 [0.49-0.71] (7)	0.43 [0.26-0.60] (6)	1.1 [0.94-1.2] (6)	0.53 [0.39-0.68] (3)	0.68 [0.36-1.0] (5)
Diss. Nitrate + Nitrite (µg N/L)		232 [215-248] (4)	244 [230-257] (7)	234 [228-240] (6)	278 [263-292] (6)	233 [223-243] (3)	244 [220-268] (5)
Dissolved Ammonia (µg N/L)		2.8 [1.2-4.3] (4)	5.9 [4.4-7.3] (7)	11.3 [9.1-13.6] (6)	1.3 [0.8-1.9] (6)	3.7 [2.2-5.1] (3)	5.0 [1.6-9.8] (5)
Diss. Reactive Silica (mg SiO_2/L)		1.74 [1.67-1.80] (4)	1.79 [1.70-1.89] (7)	1.85 [1.77-1.92] (6)	2.14 [2.04-2.23] (6)	1.95 [1.90-2.00] (3)	1.89 [1.70-2.09] (5)
Dissolved Oxygen (mg/L)		13.5 [13.3-13.6] (3)	12.8 [12.7-13.0] (7)	10.3 [9.3-11.2] (3)	9.0 [8.8-9.3] (6)	11.4 [11.0-11.7] (3)	11.4 [9.13-13.67] (5)
pH		7.94 [7.91-7.98] (4)	8.23 [8.18-8.29] (7)	7.58 [7.54-7.62] (6)	7.90 [7.80-8.01] (6)	8.07 [8.00-8.14] (3)	7.94 [7.64-8.24] (5)
Specific Conductance (µmho/cm)		166.0 [161.7-170.3] (4)	172.6 [170.5-174.6] (7)	165.7 [165.1-166.2] (6)	161.2 [159.6-162.7] (6)	177.0 [161.9-192.1] (3)	168.5 [160.7-176.3] (5)
Chloride (mg/L)		4.6 [4.1-5.2] (3)	4.4 [4.4-4.5] (7)	4.1 [2.8-5.4] (6)	4.4 [4.3-4.5] (6)	4.5 [4.3-4.6] (3)	4.4 [4.17-4.63] (5)
Sulfate (mg/L)		14.7 [14.5-14.8] (4)	14.7 [14.6-14.9] (7)	13.8 [8.00-19.5] (6)	14.0 [13.8-14.2] (6)	15.1 [14.9-15.3] (3)	14.5 [13.8-15.1] (5)
Alkalinity (mg $CaCO_3$/L)		62.8 [59.7-65.8] (4)	62.0 [61.2-62.8] (7)	61.7 [60.6-62.8] (6)	60.3 [59.8-60.9] (6)	60.0 [60.0-60.0] (3)	61.4 [59.9-62.8] (5)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - hypolimnion represented by samples with depth greater than 29 m.

**Almost isothermal conditions - hypolimnion represented by samples with depth greater than 22 m.

+Isothermal conditions - hypolimnion represented by samples with depth greater than 30.5 m.

Table 5.13. Nutrient and major ion concentrations in the epilimnion of Saginaw Bay mouth (SBM) during 1980 (stations 16, 18-21, 24, 26).

Cruise No. Dates	1* 4/16	2* 5/11	3 5/30	4 7/20	5 9/11	6 10/24	Cruise Annual Summary
Total Phosphorus (μg P/L)	4.9 [4.5-5.3] (7)	4.5 [4.0-5.0] (7)	4.8 [4.2-5.3] (13)	4.4 [3.8-4.9] (14)	3.6 [3.1-4.1] (14)	4.9 [4.6-5.3] (19)	4.5 [4.0-5.0] (6)
Total Diss. Phosphorus (μg P/L)	2.5 [2.2-2.9] (7)	2.3 [1.9-2.7] (7)	2.0 [1.9-2.2] (13)	2.2 [2.1-2.4] (14)	2.0 [1.8-2.1] (14)	2.4 [2.3-2.6] (19)	2.2 [2.0-2.5] (6)
Ortho Phosphorus (μg P/L)	0.70 [0.70-0.70] (1)	0.57 [0.43-0.71] (7)	0.70 [0.57-0.93] (13)	0.28 [0.04-0.52] (14)	0.69 [0.58-0.81] (14)	0.58 [0.53-0.64] (19)	0.59 [0.42-0.76] (6)
Diss. Nitrate + Nitrite (μg N/L)	287 [274-300] (7)	282 [275-288] (7)	289 [281-297] (13)	238 [233-243] (14)	226 [221-230] (14)	225 [249-262] (19)	263 [234-291] (6)
Dissolved Ammonia (μg N/L)	3.0 [3.0-3.0] (1)	1.3 [0.83-1.7] (7)	3.2 [2.6-3.9] (13)	4.8 [2.2-7.4] (14)	2.1 [0.32-4.0] (14)	4.2 [3.8-4.6] (19)	3.1 [1.7-4.5] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.48 [1.44-1.51] (7)	1.53 [1.50-1.56] (7)	1.16 [1.06-1.26] (13)	0.96 [0.88-1.04] (14)	0.90 [0.88-0.92] (14)	1.12 [1.08-1.16] (19)	1.19 [0.92-1.47] (6)
Dissolved Oxygen (mg/L)	14.5 [14.1-14.9] (7)	13.6 [13.3-14.0] (5)	12.4 [12.2-12.7] (13)	— — (0)	9.6 [9.3-9.8] (14)	11.1 [11.0-11.2] (19)	12.2 [9.8-14.7] (5)
pH	8.07 [8.03-8.11] (7)	8.01 [7.78-8.24] (7)	8.55 [8.50-8.59] (13)	8.26 [8.22-8.29] (14)	8.38 [8.30-8.47] (14)	8.30 [8.28-8.33] (19)	8.26 [8.05-8.47] (6)
Specific Conductance (μmho/cm)	205.0 [202.7-207.3] (7)	202.7 [202.0-203.4] (7)	214.6 [211.0-218.2] (13)	207.0 [204.7-209.3] (14)	189.8 [186.5-193.1] (14)	210.2 [209.5-210.8] (19)	204.9 [196.0-213.8] (6)
Chloride (mg/L)		5.3 [5.3-5.4] (7)	6.2 [5.9-6.4] (13)	5.8 [5.6-6.1] (14)	5.5 [5.3-5.6] (13)	5.6 [5.5-5.6] (19)	5.7 [5.3-6.1] (5)
Sulfate (mg/L)		15.7 [15.5-16.0] (7)	16.4 [16.0-16.7] (13)	15.5 [15.2-15.8] (14)	15.2 [15.0-15.4] (13)	15.6 [15.5-15.7] (19)	15.7 [15.1-16.2] (5)
Alkalinity (mg $CaCO_3$/L)	78.2 [77.7-78.8] (7)	76.7 [76.3-77.2] (7)	80.3 [78.9-81.7] (13)	80.4 [79.9-81.0] (14)	77.9 [76.8-79.0] (14)	80.1 [79.6-80.6] (19)	78.9 [77.3-80.6] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.
*Epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

Table 5.14. Nutrient and major ion concentrations in the hypolimnion of Saginaw Bay mouth (SBM) during 1980 (stations 16, 18-21, 24, 26).

Cruise No. Dates	1* 4/16	2** 5/11	3 5/30	4 7/20	5 9/11	6*** 10/24	Cruise Annual Summary
Total Phosphorus (μg P/L)	5.0 [4.1-6.0] (19)	5.0 [4.7-5.3] (19)	4.8 [4.4-5.1] (17)	5.5 [4.8-6.2] (11)	5.4 [5.0-5.7] (13)	4.6 [2.9-6.3] (3)	5.1 [4.7-5.4] (6)
Total Diss. Phosphorus (μg P/L)	2.7 [2.2-3.2] (10)	2.3 [2.1-2.6] (10)	2.0 [1.8-2.2] (17)	2.4 [2.1-2.6] (11)	2.2 [2.1-2.4] (13)	2.6 [1.5-3.8] (3)	2.4 [2.1-2.6] (6)
Ortho Phosphorus (μg P/L)	0.70 [0.70-0.70] (2)	0.57 [0.42-0.72] (10)	0.74 [0.66-0.82] (17)	0.29 [0.22-0.36] (11)	1.02 [0.86-1.19] (13)	0.67 [0.29-1.05] (3)	0.66 [0.42-0.91] (6)
Diss. Nitrate + Nitrite (μg N/L)	282 [279-285] (9)	277 [271-282] (10)	295 [291-298] (17)	297 [289-304] (11)	327 [320-334] (13)	314 [260-369] (3)	299 [279-319] (6)
Dissolved Ammonia (μg N/L)	3.0 [3.0-3.0] (2)	1.9 [1.2-2.6] (10)	3.6 [2.4-4.9] (17)	10.5 [9.1-12.0] (11)	2.1 [1.4-2.8] (13)	3.3 [1.9-4.8] (3)	4.1 [0.69-7.4] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.49 [1.46-1.51] (9)	1.52 [1.50-1.55] (10)	1.47 [1.44-1.51] (17)	1.76 [1.64-1.88] (11)	1.90 [1.80-2.01] (13)	1.80 [1.10-2.51] (3)	1.67 [1.46-1.85] (6)
Dissolved Oxygen (mg/L)	14.2 [13.8-14.6] (5)	13.9 [13.4-14.4] (5)	13.6 [13.5-13.7] (17)	11.9 [11.7-12.2] (6)	11.4 [11.1-11.7] (13)	10.8 [10.2-11.5] (2)	12.6 [11.1-14.1] (6)
pH	8.09 [8.05-8.12] (10)	8.08 [8.03-8.12] (10)	8.41 [8.35-8.48] (17)	7.88 [7.82-7.95] (11)	8.03 [7.96-8.09] (13)	8.15 [8.03-8.28] (3)	8.11 [7.92-8.29] (6)
Specific Conductance (μmho/cm)	204.5 [204.1-204.9] (10)	203.4 [202.3-204.5] (10)	211.1 [208.8-213.3] (17)	204.1 [203.7-204.4] (11)	200.8 [199.8-201.8] (13)	210.3 [208.9-211.8] (3)	205.7 [201.4-210.0] (6)
Chloride (mg/L)		5.4 [5.2-5.5] (10)	5.6 [5.5-5.7] (17)	5.5 [5.4-5.5] (10)	5.5 [5.4-5.5] (13)	5.6 [5.6-5.6] (3)	5.5 [5.4-5.6] (5)
Sulfate (mg/L)		15.7 [15.5-15.9] (10)	15.6 [15.5-15.8] (17)	15.2 [15.1-15.3] (10)	15.5 [15.4-15.6] (13)	15.9 [15.8-16.1] (3)	15.6 [15.3-15.9] (5)
Alkalinity (mg $CaCO_3$/L)	78.3 [78.0-78.6] (10)	77.4 [76.9-77.9] (10)	79.8 [79.1-80.6] (17)	80.1 [80.0-80.2] (11)	80.2 [79.6-80.8] (13)	79.7 [78.2-81.0] (3)	79.3 [78.1-80.4] (6)

The three values represent the arithmetic mean, the 95% cpnfidence interval in brackets, and the number of samples in parentheses.

*Hypolimnion represented by samples with depth equal to or greater than 32 m.

**Hypolimnion represented by samples with depth equal to or greater than 35.5 m.

***Almost isothermal - hypolimnion represented by samples with depth equal to or greater than 54 m (bottom-most layer).

Table 5.15. Nutrient and major ion concentrations in the epilimnion of nearshore area I (NS-I) Lake Huron during 1980 (stations 7, 13-14, 17, 23, 25, 94).

Cruise No. Dates	1* 4/13-4/17	2** 5/10-5/12	3 5/29-5/30	4 7/19-7/20	5*** 9/9-9/11	6*** 10/23-10/25	Cruise Annual Summary
Total Phosphorus (µg P/L)	7.4 [4.3-10.4] (7)	6.4 [5.2-7.6] (7)	5.2 [3.8-6.7] (3)	4.8 [3.6-6.0] (10)	4.6 [4.1-5.0] (13)	6.9 [6.2-7.7] (8)	5.9 [4.7-7.1] (6)
Total Diss. Phosphorus (µg P/L)	3.2 [1.5-4.9] (7)	3.0 [2.0-4.0] (7)	2.5 [1.5-3.5] (3)	2.5 [2.2-2.7] (10)	2.2 [2.0-2.4] (13)	3.2 [2.7-3.7] (8)	2.8 [2.3-3.2] (6)
Ortho Phosphorus (µg P/L)	0.77 [0.62-0.91] (3)	1.0 [0-2.2] (7)	0.80 [0.14-1.5] (3)	0.22 [0.15-0.29] (19)	0.75 [0.62-0.87] (13)	0.61 [0.53-0.70] (8)	0.69 [0.42-0.97] (6)
Diss. Nitrate + Nitrite (µg N/L)	303 [264-342] (7)	288 [260-316] (7)	292 [271-293] (3)	242 [231-253] (10)	226 [218-234] (13)	222 [211-234] (8)	260 [224-297] (6)
Dissolved Ammonia (µg N/L)	1.3 [0-2.8] (3)	1.7 [1.0-2.4] (7)	2.0 [0.0-4.5] (3)	4.2 [3.2-5.2] (10)	2.0 [1.3-2.7] (13)	3.9 [2.7-5.1] (8)	2.5 [1.2-3.8] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.22 [1.03-1.40] (7)	1.01 [0.79-1.23] (7)	0.76 [0.55-0.97] (3)	0.89 [0.80-0.98] (10)	0.89 [0.87-0.91] (13)	0.94 [0.82-1.06] (8)	0.95 [0.79-1.11] (6)
Dissolved Oxygen (mg/L)	13.8 [13.5-14.0] (3)	12.8 [12.8-12.8] (2)	11.9 [11.0-12.7] (3)	— — (0)	9.7 [9.5-9.9] (15)	11.1 [10.9-11.3] (8)	11.9 [9.9-13.8] (5)
pH	8.07 [7.94-8.25] (7)	8.21 [8.08-8.35] (7)	8.40 [8.25-8.54] (3)	8.28 [8.22-8.33] (10)	8.36 [8.30-8.41] (15)	8.30 [8.25-8.35] (8)	8.28 [8.16-8.40] (6)
Specific Conductance (µmho/cm)	211.3 [207.0-215.6] (7)	217.4 [205.0-229.9] (7)	217.7 [201.1-234.2] (3)	209.7 [206.7-212.7] (10)	193.2 [189.9-196.5] (15)	213.4 [211.1-215.6] (8)	210.4 [201.0-219.9] (6)
Chloride (mg/L)		6.4 [5.2-7.6] (7)	6.7 [6.7-6.7] (3)	6.2 [5.8-6.5] (10)	5.7 [5.6-5.9] (13)	5.9 [5.8-6.0] (8)	6.2 [5.7-6.7] (5)
Sulfate (mg/L)		17.0 [15.8-18.3] (7)	16.7 [16.2-17.2] (3)	16.3 [15.7-17.0] (10)	15.8 [15.5-16.0] (13)	15.8 [15.6-16.1] (8)	16.3 [15.7-17.0] (5)
Alkalinity (mg $CaCO_3$/L)	79.9 [78.9-80.9] (7)	80.4 [77.7-83.1] (7)	79.3 [76.5-82.2] (3)	81.2 [80.7-81.8] (10)	79.2 [78.3-80.1] (13)	82.2 [81.7-82.8] (8)	80.4 [79.1-81.6] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper (10-m layer).

**Isothermal conditions - epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

***Isothermal conditions - epilimnion represented by the upper 10-m layer.

Table 5.16. Nutrient and major ion concentrations in the hypolimnion of nearshore area I (NS-I) Lake Huron during 1980 (stations 7, 13-14, 17, 23, 25, 94).

Cruise No. Dates	1* 4/13-4/17	2** 5/10-5/12	3 5/29-5/30	4 7/19-7/20	5*** 9/9-9/11	6*** 10/23-10/25	Cruise Annual Summary
Total Phosphorus (µg P/L)	7.4 [4.5-10.3] (7)	6.7 [5.4-8.1] (7)	5.1 [4.6-5.6] (17)	6.3 [4.2-8.4] (4)	4.6 [3.7-5.5] (6)	7.6 [6.8-8.4] (5)	6.3 [5.8-6.8] (6)
Total Diss. Phosphorus (µg P/L)	2.8 [2.4-3.2] (7)	2.6 [2.2-3.0] (7)	2.3 [2.1-2.4] (17)	2.5 [2.1-2.8] (4)	2.2 [1.9-2.4] (6)	3.0 [2.6-3.4] (5)	2.6 [2.2-2.9] (6)
Ortho Phosphorus (µg P/L)	0.70 [0.70-0.70] (3)	0.41 [0.29-0.54] (7)	0.57 [0.53-0.61] (17)	0.33 [0.17-0.48] (4)	0.57 [0.46-0.68] (6)	0.60 [0.40-0.80] (6)	0.53 [0.39-0.67] (6)
Diss. Nitrate + Nitrite (µg N/L)	295 [262-328] (7)	283 [254-311] (7)	286 [279-293] (17)	272 [257-286] (4)	224 [215-233] (6)	223 [205-240] (6)	264 [230-298] (6)
Dissolved Ammonia (µg N/L)	2.3 [0.0-8.1] (3)	1.6 [0.8-2.3] (7)	2.4 [2.1-2.7] (17)	6.0 [4.7-7.3] (4)	2.5 [0.4-5.0] (6)	3.6 [2.2-5.0] (5)	3.1 [1.4-4.7] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.21 [1.03-1.39] (7)	1.03 [0.82-1.25] (7)	1.15 [1.08-1.23] (17)	1.28 [1.12-1.44] (4)	0.92 [0.89-0.95] (6)	0.90 [0.75-1.04] (5)	1.08 [0.92-1.25] (6)
Dissolved Oxygen (mg/L)	13.8 [13.3-14.3] (6)	12.9 [12.5-13.3] (7)	12.6 [12.5-12.8] (17)	12.2 [11.4-13.0] (4)	9.7 [9.1-10.3] (5)	11.1 [10.1-11.2] (6)	12.1 [10.5-13.6] (6)
pH	8.12 [8.19-8.15] (7)	8.28 [8.18-8.38] (7)	8.46 [8.42-8.50] (17)	8.18 [8.10-8.26] (4)	8.39 [8.34-8.44] (5)	8.30 [8.23-8.37] (6)	8.30 [8.15-8.42] (6)
Specific Conductance (µmho/cm)	211.0 [106.5-215.5] (7)	217.1 [205.2-229.1] (7)	214.4 [211.1-217.7] (17)	204.2 [201.9-206.6] (4)	196.5 [187.4-205.6] (4)	215.3 [212.5-218.2] (6)	209.8 [201.5-218.1] (6)
Chloride (mg/L)		6.8 [5.5-8.0] (7)	6.1 [5.8-6.3] (17)	5.7 [5.5-5.9] (4)	5.6 [5.3-5.9] (6)	5.9 [5.7-6.1] (5)	6.0 [5.4-6.6] (5)
Sulfate (mg/L)		17.0 [15.9-18.1] (7)	16.7 [16.1-16.6] (17)	16.0 [14.9-17.1] (4)	15.5 [15.0-16.0] (6)	15.7 [15.3-16.2] (5)	16.2 [15.4-17.0] (5)
Alkalinity (mg $CaCO_3$/L)	79.4 [78.7-80.1] (7)	80.4 [77.5-83.3] (7)	77.8 [76.2-79.5] (17)	80.6 [79.9-81.4] (4)	78.7 [77.0-80.4] (6)	81.8 [80.8-82.8] (6)	79.8 [78.3-81.3] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified samples - hypolimnion represented by samples with depth equal to or greater than 7 m.

**Isothermal conditions - hypolimnion represented by samples with depth equal to or greater than 7 m.

***Isothermal conditions - hypolimnion represented by samples with depth equal to or greater than 10 m.

Table 5.17. Nutrient and major ion concentrations in the epilimnion of area 4 northern basin Lake Huron (A4LH) during 1980 (stations 60, 65, 66, 67).

Cruise No. Dates	1* 4/20	2 5/16	3 6/3-6/4	4 7/24-7/25	5 9/14-9/15	6** 10/30-11/1	Cruise Annual Summary
Total Phosphorus (μg P/L)	6.1 [3.1-9.1] (4)	5.1 [3.3-6.8] (4)	4.7 [3.3-6.0] (3)	4.7 [3.8-5.6] (6)	5.0 [4.6-5.4] (8)	5.4 [4.7-6.0] (14)	5.2 [4.6-5.7] (6)
Total Diss. Phosphorus (μg P/L)	3.8 [2.1-5.5] (4)	2.1 [1.6-2.6] (4)	1.9 [1.5-2.3] (3)	2.4 [2.2-2.7] (6)	2.1 [2.0-2.2] (8)	2.0 [1.8-2.2] (14)	2.4 [1.6-3.1] (6)
Ortho Phosphorus (μg P/L)	1.0 [0.55-1.45] (4)	0.52 [0.29-0.76] (4)	0.83 [0.69-0.98] (3)	0.40 [0.27-0.53] (6)	0.88 [0.62-1.10] (8)	0.63 [0.56-0.70] (14)	0.71 [0.47-0.95] (6)
Diss. Nitrate + Nitrite (μg N/L)	280 [268-291] (4)	276 [264-288] (4)	266 [234-297] (3)	204 [165-243] (6)	245 [222-268] (8)	293 [280-305] (14)	261 [227-294] (6)
Dissolved Ammonia (μg N/L)	2.8 [1.2-4.3] (4)	1.8 [1.0-2.5] (4)	3.7 [0.0-11.2] (3)	3.2 [1.9-4.4] (6)	1.1 [0.8-1.4] (8)	1.0 [1.0-1.0] (14)	2.3 [1.1-3.5] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.64 [1.45-1.83] (4)	1.66 [1.40-1.91] (4)	1.75 [1.21-2.29] (3)	0.91 [0.54-1.28] (6)	1.18 [1.49-1.65] (8)	1.57 [1.10-1.79] (14)	1.45 [1.10-1.80] (6)
Dissolved Oxygen (mg/L)	14.2 [14.2-14.2] (1)	— — (0)	11.8 [11.2-12.5] (3)	— — (0)	10.3 [10.0-10.6] (8)	12.3 [12.0-12.5] (14)	12.4 [10.5-14.3] (5)
pH	8.06 [7.86-8.27] (4)	7.90 [7.69-8.11] (4)	8.28 [8.06-8.50] (3)	8.26 [8.11-8.40] (6)	8.16 [8.06-8.26] (8)	8.19 [8.14-8.24] (14)	8.14 [7.99-8.29] (6)
Specific Conductance (μmho/cm)	183.5 [159.4-207.6] (4)	176.8 [131.3-222.2] (4)	138.7 [119.4-158.0] (3)	206.7 [170.7-242.7] (6)	179.8 [165.1-194.4] (8)	205.5 [199.7-211.3] (14)	181.8 [155.8-207.8] (6)
Chloride (mg/L)		4.5 [2.6-6.3] (4)	2.9 [2.1-3.6] (3)	5.5 [3.6-7.5] (5)	5.0 [4.3-5.7] (8)	5.4 [5.1-5.7] (14)	4.7 [3.3-6.0] (5)
Sulfate (mg/L)		12.6 [7.1-18.1] (4)	8.2 [4.90-11.4] (3)	15.0 [10.9-19.0] (5)	14.2 [12.9-15.6] (8)	15.3 [14.8-15.8] (14)	13.1 [9.4-16.7] (5)
Alkalinity (mg $CaCO_3$/L)	71.0 [61.2-80.9] (4)	66.5 [51.1-81.9] (4)	56.7 [52.9-60.5] (3)	83.3 [67.2-99.5] (6)	71.9 [65.5-78.2] (8)	78.6 [75.9-81.3] (14)	71.3 [61.5-81.1] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

**Almost Isothermal conditions - epilimnion represented by upper 10-m layer.

Table 5.18. Nutrient and major ion concentrations in the hypolimnion of area 4 northern basin Lake Huron (A4LH) during 1980 (stations 60, 66, 67).

Cruise No. Dates	1* 4/20	2 5/16	3 6/3-6/4	4 7/24-7/25	5 9/14-9/15	6** 10/30-11/1	Cruise Annual Summary
Total Phosphorus (µg P/L)	6.4 [5.1-7.6] (6)	4.7 [4.0-5.4] (5)	4.3 [3.6-4.9] (7)	6.0 [4.7-7.3] (8)	5.6 [4.8-6.4] (3)	10.0 [0.0-75.4] (2)	6.2 [4.0-8.3] (6)
Total Diss. Phosphorus (µg P/L)	3.4 [2.2-4.5] (6)	2.0 [1.8-2.3] (5)	1.9 [1.7-2.0] (7)	2.5 [2.3-2.7] (8)	1.9 [1.5-2.3] (3)	2.2 [0.0-4.7] (2)	2.3 [1.7-2.9] (6)
Ortho Phosphorus (µg P/L)	0.92 [0.60-1.2] (6)	0.60 [0.48-0.72] (5)	0.90 [0.81-0.99] (7)	0.56 [0.41-0.71] (8)	0.90 [0.65-1.1] (3)	0.90 [0.0-2.2] (2)	0.80 [0.62-0.97] (6)
Diss. Nitrate + Nitrite (µg N/L)	274 [266-282] (6)	271 [258-284] (5)	278 [268-288] (7)	289 [280-299] (8)	319 [284-353] (3)	327 [251-403] (2)	293 [268-318] (6)
Dissolved Ammonia (µg N/L)	2.5 [1.6-3.4] (6)	2.2 [1.2-3.2] (5)	3.1 [1.5-4.8] (7)	8.1 [5.7-10.6] (8)	1.0 [1.0-1.0] (3)	1.0 [1.0-1.0] (2)	3.0 [0.2-5.8] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.61 [1.50-1.72] (6)	1.53 [1.45-1.61] (5)	1.57 [1.51-1.64] (7)	1.67 [1.52-1.83] (8)	1.80 [1.47-2.14] (3)	1.80 [0.91-2.69] (2)	1.66 [1.54-1.78] (6)
Dissolved Oxygen (mg/L)	13.9 [13.6-14.3] (3)	13.5 [12.8-14.2] (3)	13.2 [13.0-13.3] (7)	12.6 [12.3-13.0] (8)	12.1 [11.6-12.6] (3)	12.4 [11.1-13.7] (2)	12.97 [12.3-13.7] (6)
pH	8.04 [8.02-8.06] (6)	7.98 [7.92-8.04] (5)	8.24 [8.20-8.28] (7)	7.85 [7.77-7.92] (8)	7.99 [7.87-8.12] (3)	8.04 [7.73-8.36] (2)	8.03 [7.88-8.16] (6)
Specific Conductance (µmho/cm)	190.0 [177.2-202.8] (6)	197.0 [187.0-207.0] (5)	195.3 [188.2-202.4] (7)	194.6 [192.0-197.2] (8)	192.3 [190.9-193.8] (3)	211.5 [192.4-230.6] (2)	196.8 [188.8-204.8] (6)
Chloride (mg/L)		5.2 [4.9-5.6] (5)	5.1 [4.7-5.4] (7)	5.0 [4.9-5.2] (6)	5.4 [5.3-5.6] (3)	5.6 [4.9-6.2] (2)	5.3 [5.0-5.6] (5)
Sulfate (mg/L)		14.6 [13.7-15.6] (5)	14.4 [13.5-15.2] (7)	14.2 [13.9-14.5] (6)	15.3 [15.0-15.6] (3)	15.6 [15.0-16.3] (2)	14.8 [14.0-15.6] (5)
Alkalinity (mg $CaCO_3$/L)	74.0 [69.1-78.9] (6)	74.0 [70.2-77.8] (5)	75.6 [73.0-78.2] (7)	77.7 [76.5-78.8] (8)	77.3 [75.9-78.8] (3)	79.5 [73.1-85.9] (2)	76.4 [74.0-78.7] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Unstratified conditions - hypolimnion represented by samples with depth equal to or greater than 33 m.

**Almost Isothermal conditions - hypolimnion represented by samples with depth equal to or greater than 62.5 m.

Table 5.19. Nutrient and major ion concentrations in the epilimnion of area 5 northern basin Lake Huron (A5LH) during 1980 (stations 56, 62, 63, 64).

Cruise No. Dates	1* 4/19–4/20	2** 5/15–5/16	3 6/4	4 7/24–7/25	5 9/14	6* 10/31	Cruise Annual Summary
Total Phosphorus (μg P/L)	7.4 [5.8–9.0] (4)	5.2 [4.5–5.9] (8)	4.8 [4.5–5.2] (11)	4.3 [3.9–4.8] (9)	5.4 [4.5–6.3] (8)	5.6 [4.1–7.1] (4)	5.5 [4.3–6.6] (6)
Total Diss. Phosphorus (μg P/L)	4.2 [1.9–6.4] (4)	2.3 [2.0–2.5] (8)	2.1 [1.9–2.2] (11)	2.3 [2.0–2.6] (9)	2.2 [2.1–2.4] (8)	2.3 [1.9–2.6] (4)	2.6 [1.7–3.4] (6)
Ortho Phosphorus (μg P/L)	0.95 [0.23–1.70] (4)	0.70 [0.57–0.83] (8)	0.80 [0.80–0.80] (11)	0.48 [0.44–0.51] (4)	0.75 [0.71–0.79] (8)	0.48 [0.40–0.55] (4)	0.69 [0.49–0.89] (6)
Diss. Nitrate + Nitrite (μg N/L)	249 [199–299] (4)	230 [213–247] (8)	232 [215–248] (11)	179 [150–208] (9)	212 [194–229] (8)	217 [129–305] (4)	220 [195–245] (6)
Dissolved Ammonia (μg N/L)	1.8 [1.0–2.5] (4)	1.2 [0.9–1.6] (8)	3.3 [1.1–5.5] (11)	1.9 [0.5–3.2] (9)	1.0 [1.0–1.0] (8)	1.5 [0.6–2.4] (4)	1.8 [0.9–2.6] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.34 [0.92–1.76] (4)	1.13 [0.98–1.27] (8)	1.50 [1.50–1.50] (11)	0.64 [0.39–0.90] (9)	1.01 [0.90–1.22] (8)	1.25 [0.82–1.66] (4)	1.15 [0.83–1.46] (6)
Dissolved Oxygen (mg/L)	14.2 [14.2–14.2] (1)	13.2 [12.6–13.9] (2)	12.4 [12.3–12.6] (11)	9.8 [9.8–9.8] (1)	10.1 [9.80–10.4] (8)	11.7 [11.1–12.2] (4)	11.9 [10.1–13.7] (6)
pH	8.16 [8.12–8.20] (4)	8.16 [8.19–8.24] (8)	8.38 [8.31–8.44] (11)	8.34 [8.25–8.43] (9)	8.17 [8.12–8.21] (8)	8.54 [8.30–8.65] (4)	8.30 [8.12–8.46] (6)
Specific Conductance (μmho/cm)	219.5 [188.6–250.4] (4)	225.1 [215.4–234.8] (8)	229.8 [221.5–238.2] (11)	229.9 [202.3–257.5] (9)	212.5 [201.6–223.4] (8)	240.8 [195.7–285.8] (4)	226.3 [216.1–236.5] (6)
Chloride (mg/L)		6.3 [5.8–6.7] (8)	6.3 [5.9–6.7] (11)	5.8 [4.0–7.7] (4)	6.3 [5.7–6.8] (8)	6.7 [4.6–8.8] (4)	6.3 [5.9–6.7] (5)
Sulfate (mg/L)		16.7 [15.9–17.5] (8)	17.2 [16.3–18.0] (11)	15.1 [11.0–19.1] (4)	16.7 [15.6–17.7] (8)	17.8 [13.9–21.6] (4)	16.7 [15.5–17.9] (5)
Alkalinity (mg $CaCO_3$/L)	86.2 [73.1–99.4] (4)	85.6 [81.9–89.3] (8)	88.2 [83.6–92.8] (11)	92.1 [80.3–103.8] (9)	86.5 [82.0–91.0] (8)	91.2 [73.8–109.] (4)	88.3 [85.4–91.2] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Isothermal conditions - epilimnion represented by surface samples which were the only samples in the upper 10-m layer.

**Isothermal conditions - epilimnion represented by the upper 10-m layer.

Table 5.20. Nutrient and major ion concentrations in the hypolimnion of area 5 northern basin Lake Huron (A5LH) during 1980 (stations 56, 62, 63, 64).

Cruise No. Dates	1* 4/19-4/20	2** 5/15-5/16	3 6/4	4 7/24-7/25	5 9/14	6* 10/31	Cruise Annual Summary
Total Phosphorus (μg P/L)	7.0 [0.06-14.0] (2)	7.2 [0.0-2.8] (2)	4.4 [4.2-4.6] (3)	5.7 [4.4-6.9] (5)	5.9 [4.7-7.1] (4)	5.8 [4.1-7.4] (4)	6.0 [4.9-7.1] (6)
Total Diss. Phosphorus (μg P/L)	6.8 [0.0-27.0] (2)	1.8 [0.53-3.1] (2)	2.3 [1.5-3.0] (3)	2.5 [2.2-2.7] (5)	2.2 [1.9-2.5] (4)	2.2 [1.8-2.6] (4)	3.0 [1.0-5.0] (6)
Ortho Phosphorus (μg P/L)	1.8 [0.00-13.9] (2)	0.65 [0.01-1.3] (2)	0.80 [0.80-0.80] (3)	0.52 [0.38-0.66] (5)	1.2 [0.87-1.40] (4)	0.50 [0.50-0.50] (4)	0.91 [0.38-1.44] (6)
Diss. Nitrate + Nitrite (μg N/L)	279 [253-304] (2)	274 [274-274] (2)	284 [274-294] (3)	282 [258-305] (5)	323 [311-334] (4)	225 [129-321] (4)	278 [245-311] (6)
Dissolved Ammonia (μg N/L)	3.0 [0.0-15.7] (2)	2.0 [2.0-2.0] (2)	3.3 [0.5-6.2] (3)	3.0 [0.0-6.5] (5)	1.0 [1.0-1.0] (4)	1.5 [0.6-2.4] (4)	2.3 [1.3-3.3] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.58 [1.33-1.83] (2)	1.53 [1.53-1.53] (2)	1.50 [1.50-1.50] (3)	1.69 [1.34-2.05] (5)	1.84 [1.73-1.95] (4)	1.27 [0.84-1.70] (4)	1.57 [1.37-1.77] (6)
Dissolved Oxygen (mg/L)	14.0 [14.0-14.0] (2)	13.7 [13.7-13.7] (1)	13.2 [13.1-13.4] (3)	11.9 [8.8-15.1] (2)	11.9 [11.8-12.1] (4)	11.8 [11.4-12.2] (4)	12.8 [11.7-13.8] (6)
pH	8.13 [8.13-8.13] (2)	8.08 [7.95-8.21] (2)	8.35 [8.34-8.37] (3)	7.88 [7.73-8.02] (5)	8.00 [7.93-8.07] (4)	8.42 [8.21-8.62] (4)	8.14 [7.93-8.36] (6)
Specific Conductance (μmho/cm)	200.0 [200.0-200.0] (2)	200.0 [200.0-200.0] (2)	205.0 [202.5-207.5] (3)	200.0 [195.1-204.9] (5)	195.3 [192.2-198.3] (4)	236.8 [191.2-282.3] (4)	206.2 [190.1-222.3] (6)
Chloride (mg/L)		5.2 [5.2-5.2] (2)	5.4 [5.2-5.6] (3)	5.5 [5.4-5.7] (4)	5.2 [5.2-5.3] (4)	6.7 [4.8-8.6] (4)	5.6 [4.8-6.4] (5)
Sulfate (mg/L)		14.9 [14.9-14.9] (2)	15.1 [14.5-15.8] (3)	14.7 [14.2-15.1] (4)	14.8 [14.6-14.9] (4)	17.7 [14.2-21.2] (4)	15.4 [13.9-17.0] (5)
Alkalinity (mg $CaCO_3$/L)	77.0 [77.0-77.0] (2)	76.5 [70.1-82.9] (2)	80.0 [80.0-80.0] (3)	79.9 [77.9-81.9] (5)	78.0 [76.7-79.3] (4)	90.5 [71.0-110.0] (4)	80.3 [74.9-85.8] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Isothermal conditions - hypolimnion represented by bottom layer equal to or greater than 35 m.

**Isothermal conditions - hypolimnion represented by bottom layer equal to or greater than 36 m.

Table 5.21. Nutrient and major ion concentrations in the epilimnion of southern basin Lake Huron (SBLH) during 1980 (stations 6, 9, 12, 15, 90-93).

Cruise No. Dates	1* 4/13-4/15	2* 5/10-5/11	3 5/29	4 7/19	5 9/9-9/11	6 10/23-10/25	Cruise Annual Summary
Total Phosphorus (µg P/L)	4.0 [3.3-4.8] (8)	4.8 [4.4-5.2] (8)	5.0 [4.4-5.7] (9)	3.7 [3.2-4.2] (15)	3.9 [3.4-4.3] (14)	4.8 [4.5-5.1] (20)	4.4 [3.8-5.0] (6)
Total Diss. Phosphorus (µg P/L)	2.7 [1.8-3.5] (8)	2.2 [2.0-2.3] (8)	2.3 [2.1-2.5] (9)	2.3 [2.2-2.4] (15)	2.1 [2.0-2.3] (14)	2.8 [2.6-3.0] (19)	2.4 [2.1-2.7] (6)
Ortho Phosphorus (µg P/L)	0.80 [0.34-1.26] (5)	0.54 [0.28-0.79] (8)1	0.84 [0.66-1.03] (9)	0.32 [0.24-0.40] (15)	0.66 [0.59-0.73] (14)	0.72 [0.66-0.79] (20)	0.65 [0.44-0.86] (6)
Diss. Nitrate + Nitrite (µg N/L)	284 [272-296] (8)	286 [284-289] (8)	294 [286-303] (9)	271 [266-274] (15)	240 [229-251] (14)	255 [251-258] (20)	271.7 [250.0-293.4] (6)
Dissolved Ammonia (µg N/L)	1.8 [0.76-2.8] (5)	1.3 [0.79-1.9] (6)	2.3 [1.7-3.0] (9)	3.7 [3.2-4.3] (15)	2.6 [1.8-3.3] (14)	5.2 [4.6-5.9] (20)	2.8 [1.3-4.3] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.50 [1.45-1.55] (8)	1.47 [1.45-1.48] (8)	1.33 [1.16-1.48] (9)	1.03 [0.98-1.08] (15)	0.89 [0.83-0.95] (14)	1.09 [1.05-1.14] (20)	1.22 [0.95-1.48] (6)
Dissolved Oxygen (mg/L)	14.2 [11.1-17.4] (2)	13.8 [13.2-14.5] (2)	13.4 [12.8-13.9] (9)	— — (0)	9.5 [9.1-10.0] (14)	10.8 [10.7-11.0] (20)	12.3 [9.8-14.9] (5)
pH	8.02 [7.94-8.09] (8)	8.06 [8.02-8.09] (8)	8.31 [8.26-8.35] (9)	8.30 [8.27-8.32] (15)	8.38 [8.30-8.47] (14)	8.31 [8.26-8.36] (20)	8.23 [8.07-8.39] (6)
Specific Conductance (µmho/cm)	203.1 [202.4-203.8] (8)	203.5 [202.6-204.4] (8)	211.9 [207.4-216.4] (9)	206.4 [205.4-207.4] (15)	197.1 [193.8-200.4] (14)	210.7 [209.3-212.0] (18)	205.4 [199.7-211.2] (6)
Chloride (mg/L)		5.5 [5.4-5.6] (8)	5.9 [5.5-6.2] (9)	5.7 [5.6-5.9] (15)	5.9 [5.8-6.0] (14)	5.6 [5.6-5.7] (20)	5.7 [5.5-5.9] (5)
Sulfate (mg/L)		15.7 [15.6-15.8] (8)	15.9 [15.5-16.3] (9)	15.9 [15.7-16.1] (15)	16.2 [16.0-16.3] (14)	15.7 [15.6-15.8] (20)	15.9 [15.6-16.1] (5)
Alkalinity (mg $CaCO_3$/L)	76.3 [75.6-76.9] (8)	77.6 [77.0-78.2] (8)	75.4 [73.9-77.0] (9)	79.7 [79.4-80.0] (15)	78.5 [78.0-79.0] (14)	80.8 [80.4-81.3] (20)	78.0 [75.9-80.2] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Epilimnion represented by surface samples which were the only samples in the upper 10 m.

Table 5.22. Nutrient and major ion concentrations in the hypolimnion of southern basin Lake Huron (SBLH) during 1980 (stations 6, 9, 12, 15, 90-93).

Cruise No. Dates	1* 4/13-4/15	2** 5/10-5/11	3 5/29	4 7/19	5 9/9-9/11	6 10/23-10/25	Cruise Annual Summary
Total Phosphorus (μg P/L)	4.3 [3.7-4.9] (13)	5.8 [4.8-6.8] (13)	5.1 [4.8-5.4] (23)	5.9 [5.4-6.5] (24)	6.4 [5.4-7.5] (19)	5.0 [4.7-5.4] (12)	5.4 [4.6-6.2] (6)
Total Diss. Phosphorus (μg P/L)	2.4 [1.7-3.2] (13)	2.2 [2.1-2.4] (13)	2.3 [2.1-2.4] (23)	2.9 [2.7-3.1] (24)	2.6 [2.5-2.7] (19)	3.2 [2.6-3.8] (12)	2.6 [2.2-3.0] (6)
Ortho Phosphorus (μg P/L)	0.84 [0.65-1.03] (7)	0.59 [0.49-0.70] (13)	0.96 [0.81-1.12] (23)	0.48 [0.30-0.66] (23)	1.23 [1.05-1.42] (19)	1.07 [0.92-1.21] (12)	0.86 [0.56-1.16] (6)
Diss. Nitrate + Nitrite (μg N/L)	279 [271-286] (13)	287 [283-292] (13)	293 [292-295] (23)	298 [290-306] (24)	330 [319-341] (19)	332 [330-335] (12)	303.2 [279.5-326.8] (6)
Dissolved Ammonia (μg N/L)	2.6 [1.4-3.7] (7)	1.9 [1.4-2.4] (90	3.0 [2.4-3.5] (23)	11.4 [9.1-13.7] (24)	2.9 [1.7-4.2] (19)	3.7 [2.7-4.6] (12)	4.2 [1.2-6.3] (6)
Diss. Reactive Silica (mg SiO_2/L)	1.50 [1.47-1.53] (13)	1.52 [1.48-1.55] (12)	1.47 [1.46-1.49] (23)	1.66 [1.47-1.85] (24)	1.92 [1.71-2.13] (19)	1.96 [1.89-2.02] (12)	1.67 [1.44-1.90] (6)
Dissolved Oxygen (mg/L)	14.4 [14.1-14.8] (7)	14.1 [13.8-14.4] (7)	13.9 [13.8-14.0] (23)	11.7 [11.0-12.4] (7)	11.6 [11.3-12.0] (19)	11.3 [11.2-11.4] (12)	12.8 [11.3-14.3] (6)
pH	8.03 [7.97-8.09] (13)	8.04 [8.02-8.06] (13)	8.27 [8.24-8.29] (23)	8.00 [7.92-8.09] (24)	7.93 [7.83-8.03] (19)	8.13 [8.09-8.17] (12)	8.07 [7.94-8.19] (6)
Specific Conductance (μmho/cm)	203.4 [202.7-204.1] (13)	203.7 [203.0-204.4] (13)	210.0 [208.9-211.0] (23)	204.3 [203.7-204.9] (24)	201.3 [199.9-202.7] (19)	211.3 [210.0-212.7] (9)	205.7 [201.5-209.9] (6)
Chloride (mg/L)		5.5 [5.4-5.6] (13)	5.6 [5.5-5.7] (23)	5.5 [5.4-5.5] (23)	5.5 [5.5-5.6] (19)	5.6 [5.5-5.7] (12)	5.5 [5.5-5.6] (5)
Sulfate (mg/L)		15.7 [15.6-15.8] (13)	15.7 [15.6-15.8] (23)	15.5 [15.4-15.6] (23)	15.9 [15.3-16.5] (19)	15.9 [15.6-16.1] (12)	15.7 [15.5-15.9] (5)
Alkalinity (mg $CaCO_3$/L)	76.6 [76.2-77.0] (13)	77.7 [77.3-78.1] (13)	75.4 [74.4-76.3] (23)	80.3 [80.1-80.6] (24)	78.2 [77.6-78.7] (19)	80.2 [79.6-80.9] (12)	78.1 [76.0-80.1] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

*Hypolimnion represented by samples with depth equal to or greater than 44 m.

**Hypolimnion represented by samples with depth equal to or greater than 50 m.

Table 5.23. Nutrient and major ion concentrations in the epilimnion of river area station 69 during 1980.

Cruise No. Dates	1* 4/20	2* 5/16	3* 6/4	4+ 7/26	5* 9/15	6* 10/31	Cruise Annual Summary
Total Phosphorus (µg P/L)	7.0 [7.0-7.0] (1)	10.0 [10.0-10.0] (1)	6.6 [6.6-6.6] (1)	8.5 [8.5-8.5] (1)	9.5 [9.5-9.5] (1)	9.0 [9.0-9.0] (1)	8.4 [7.0-9.9] (6)
Total Diss. Phosphorus (µg P/L)	2.9 [2.9-2.9] (1)	1.9 [1.9-1.9] (1)	3.0 [3.0-3.0] (1)	3.2 [3.2-3.2] (1)	2.0 [2.0-2.0] (1)	2.2 [2.2-2.2] (1)	2.53 [1.9-3.1] (6)
Ortho Phosphorus (µg P/L)	1.3 [1.3-1.3] (1)	0.40 [0.40-0.40] (1)	0.80 [0.80-0.80] (1)	0.80 [0.80-0.80] (1)	1.0 [1.0-1.0] (1)	0.70 [0.70-0.70] (1)	0.83 [0.52-1.2] (6)
Diss. Nitrate + Nitrite (µg N/L)	273 [273-273] (1)	246 [246-246] (1)	252 [252-252] (1)	226 [226-226] (1)	249 [249-249] (1)	278 [278-278] (1)	254 [234-274] (6)
Dissolved Ammonia (µg N/L)	0.8 [0.8-0.8] (1)	1.0 [1.0-1.0] (1)	1.0 [1.0-1.0] (1)	0.9 [0.9-0.9] (1)	1.1 [1.1-1.1] (1)	3.0 [3.0-3.0] (1)	1.30 [0.4-2.2] (6)
Diss. Reactive Silica (mg SiO_2/L)	2.21 [2.21-2.21] (1)	2.11 [2.11-2.11] (1)	2.10 [2.10-2.10] (1)	2.13 [2.13-2.13] (1)	2.15 [2.15-2.15] (1)	2.21 [2.21-2.21] (1)	2.15 [2.10-2.20] (6)
Dissolved Oxygen (mg/L)	— — (0)	— — (0)	11.6 [11.6-11.6] (1)	— — (0)	9.7 [9.7-9.7] (1)	12.3 [12.3-12.3] (1)	11.2 [7.8-14.6] (3)
pH	7.80 [7.80-7.80] (1)	7.83 [7.83-7.83] (1)	8.21 [8.21-8.21] (1)	7.84 [7.84-7.84] (1)	8.09 [8.09-8.09] (1)	8.37 [8.37-8.37] (1)	8.02 [7.77-8.27] (6)
Specific Conductance (µmho/cm)	94 [94-94] (1)	98 [98-98] (1)	98 [98-98] (1)	100 [100-100] (1)	95 [95-95] (1)	99 [99-99] (1)	97.3 [94.9-99.8] (6)
Chloride (mg/L)		1.5 [1.5-1.5] (1)	1.3 [1.3-1.3] (1)	1.3 [1.3-1.3] (1)	— — (0)	1.3 [1.3-1.3] (1)	1.4 [1.2-1.5] (4)
Sulfate (mg/L)		3.0 [3.0-3.0] (1)	3.3 [3.3-3.3] (1)	3.1 [3.1-3.1] (1)	— — (0)	3.3 [3.3-3.3] (1)	3.2 [2.9-3.4] (4)
Alkalinity (mg $CaCO_3$/L)	40.0 [40.0-40.0] (1)	42.0 [42.0-42.0] (1)	45.0 [45.0-45.0] (1)	44.0 [44.0-44.0] (1)	43.0 [43.0-43.0] (1)	45.0 [45.0-45.0] (1)	43.2 [41.1-45.2] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.
*Epilimnion represented by surface samples.
+Stratified conditions.

Table 5.24. Nutrient and major ion concentrations in the hypolimnion of river area station 69 during 1980.

Cruise No. Dates	1*	2*	3*	4+	5*	6*	Cruise Annual Summary
Total Phosphorus (µg P/L)	7.2 [7.2-7.2] (1)	10.1 [10.1-10.1] (1)	7.6 [7.6-7.6] (1)	9.3 [9.3-9.3] (1)	10.3 [10.3-10.3] (1)	12.2 [12.2-12.2] (1)	9.4 [7.5-11.4] (6)
Total Diss. Phosphorus (µg P/L)	2.8 [2.8-2.8] (1)	6.0 [6.0-6.0] (1)	2.3 [2.3-2.3] (1)	4.0 [4.0-4.0] (1)	2.0 [2.0-2.0] (1)	2.2 [2.2-2.2] (1)	3.2 [1.6-4.8] (6)
Ortho Phosphorus (µg P/L)	0.70 [0.70-0.70] (1)	0.40 [0.40-0.40] (1)	0.80 [0.80-0.80] (1)	0.50 [0.50-0.50] (1)	2.20 [2.20-2.20] (1)	0.70 [0.70-0.70] (1)	0.88 [0.20-1.58] (6)
Diss. Nitrate + Nitrite (µg N/L)	265 [265-265] (1)	245 [245-245] (1)	255 [255-255] (1)	280 [280-280] (1)	251 [251-251] (1)	278 [278-278] (1)	262 [247-278] (6)
Dissolved Ammonia (µg N/L)	0.80 [0.80-0.80] (1)	2.0 [2.0-2.0] (1)	1.0 [1.0-1.0] (1)	1.7 [1.7-1.7] (1)	1.7 [1.7-1.7] (1)	3.0 [3.0-3.0] (1)	1.7 [0.9-2.5] (6)
Diss. Reactive Silica (mg SiO_2/L)	2.24 [2.24-2.24] (1)	2.13 [2.13-2.13] (1)	2.11 [2.11-2.11] (1)	1.91 [1.91-1.91] (1)	2.18 [2.18-2.18] (1)	2.21 [2.21-2.21] (1)	2.13 [2.00-2.25] (6)
Dissolved Oxygen (mg/L)	14.8 [14.8-14.8] (1)	12.2 [12.2-12.2] (1)	11.7 [11.7-11.7] (1)	11.0 [11.0-11.0] (1)	9.7 [9.7-9.7] (1)	12.1 [12.1-12.1] (1)	11.9 [10.2-13.7] (6)
pH	7.78 [7.78-7.78] (1)	7.89 [7.89-7.89] (1)	8.20 [8.20-8.20] (1)	7.65 [7.65-7.65] (1)	8.10 [8.10-8.10] (1)	8.28 [8.28-8.28] (1)	7.98 [7.72-8.24] (6)
Specific Conductance (µmho/cm)	94 [94-94] (1)	98 [98-98] (1)	100 [100-100] (1)	173 [173-173] (1)	95 [95-95] (1)	101 [101-101] (1)	110.2 [77.7-142.6] (6)
Chloride (mg/L)		1.4 [1.4-1.4] (1)	1.3 [1.3-1.3] (1)	4.2 [4.2-4.2] (1)	— — (0)	1.4 [1.4-1.4] (1)	2.1 [0.0-4.3] (4)
Sulfate (mg/L)		2.8 [2.8-2.8] (1)	3.2 [3.2-3.2] (1)	13.0 [13.0-13.0] (1)	— — (0)	3.3 [3.3-3.3] (1)	5.58 [0.0-13.5] (4)
Alkalinity (mg $CaCO_3$/L)	40.0 [40.0-40.0] (1)	42.0 [42.0-42.0] (1)	45.0 [45.0-45.0] (1)	71.0 [71.0-71.0] (1)	43.0 [43.0-43.0] (1)	45.0 [45.0-45.0] (1)	47.67 [35.5-59.8] (6)

The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.
*Isothermal conditions - hypolimnion represented by bottom samples.
+Stratified conditions.

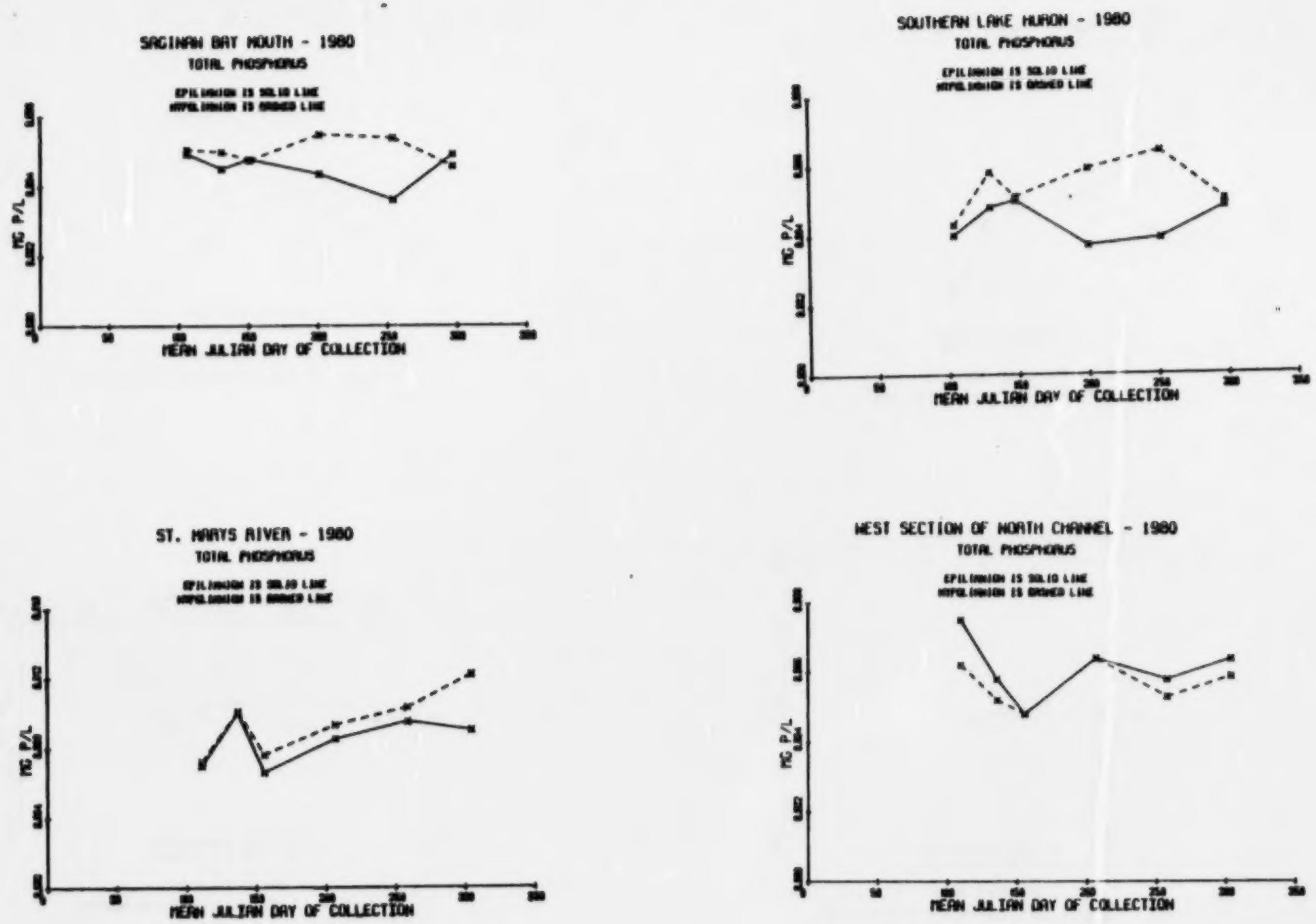


Figure 5.2. Time variation of total phosphorus during 1980.

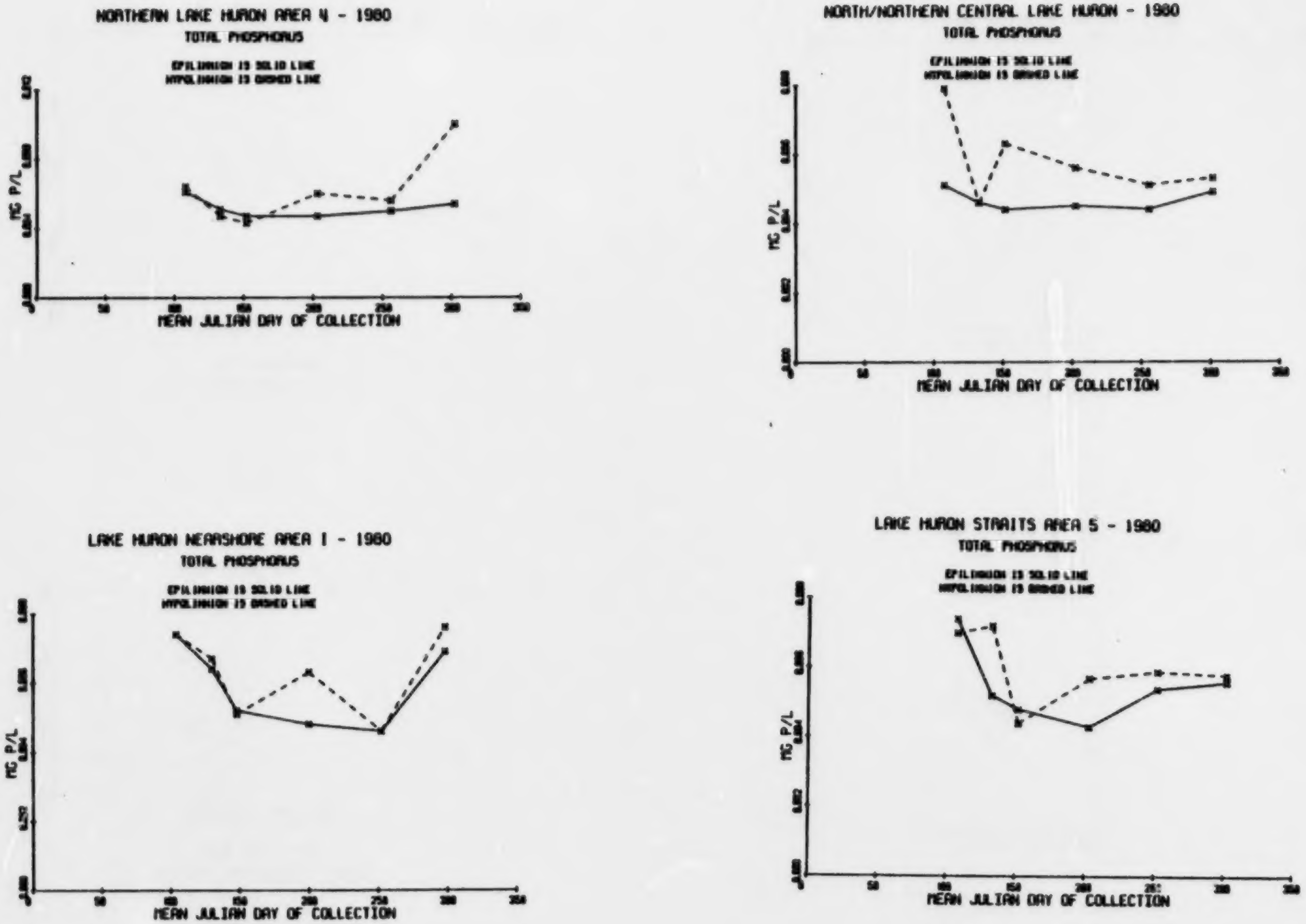
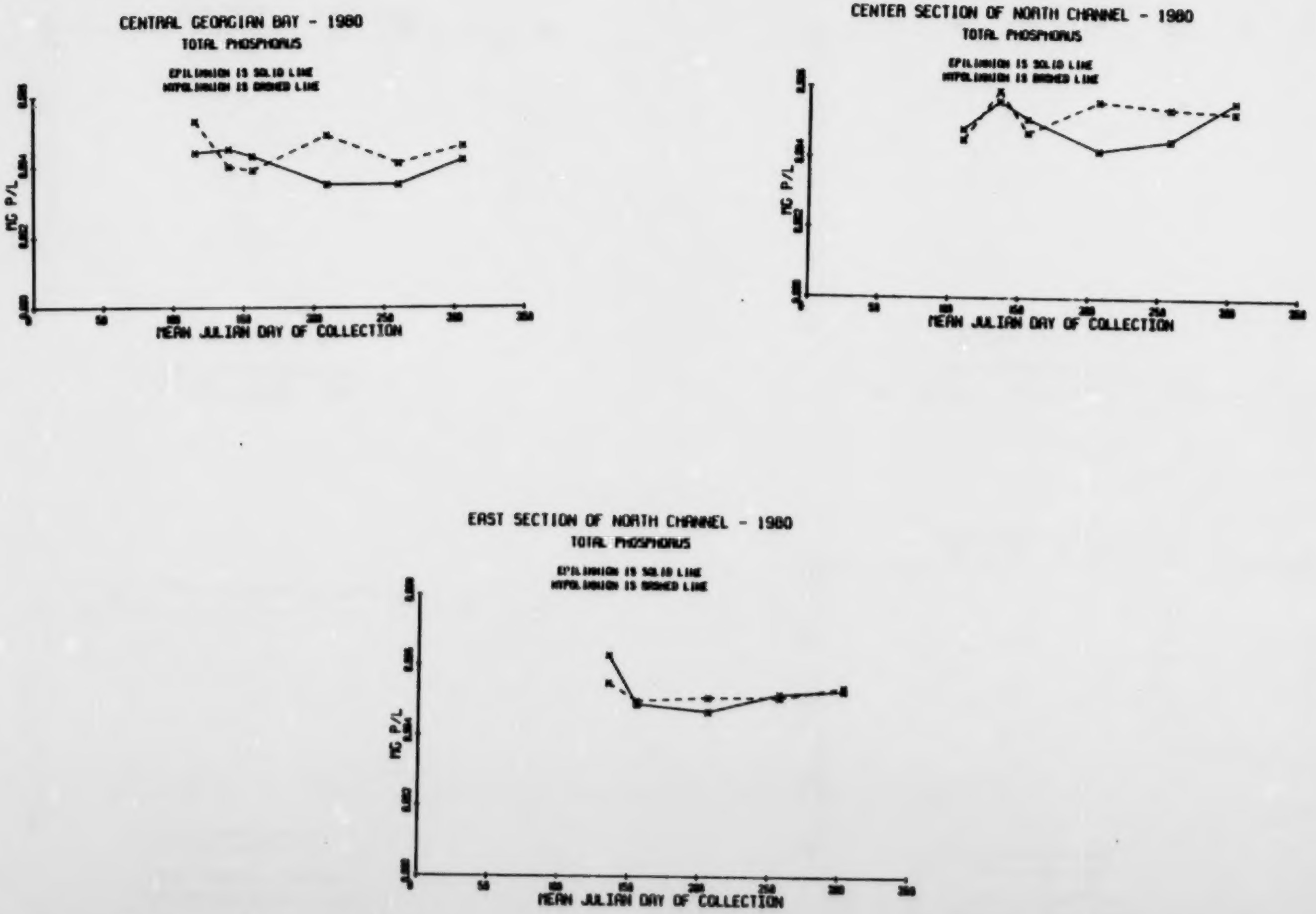


Figure 5.2. (Continued).



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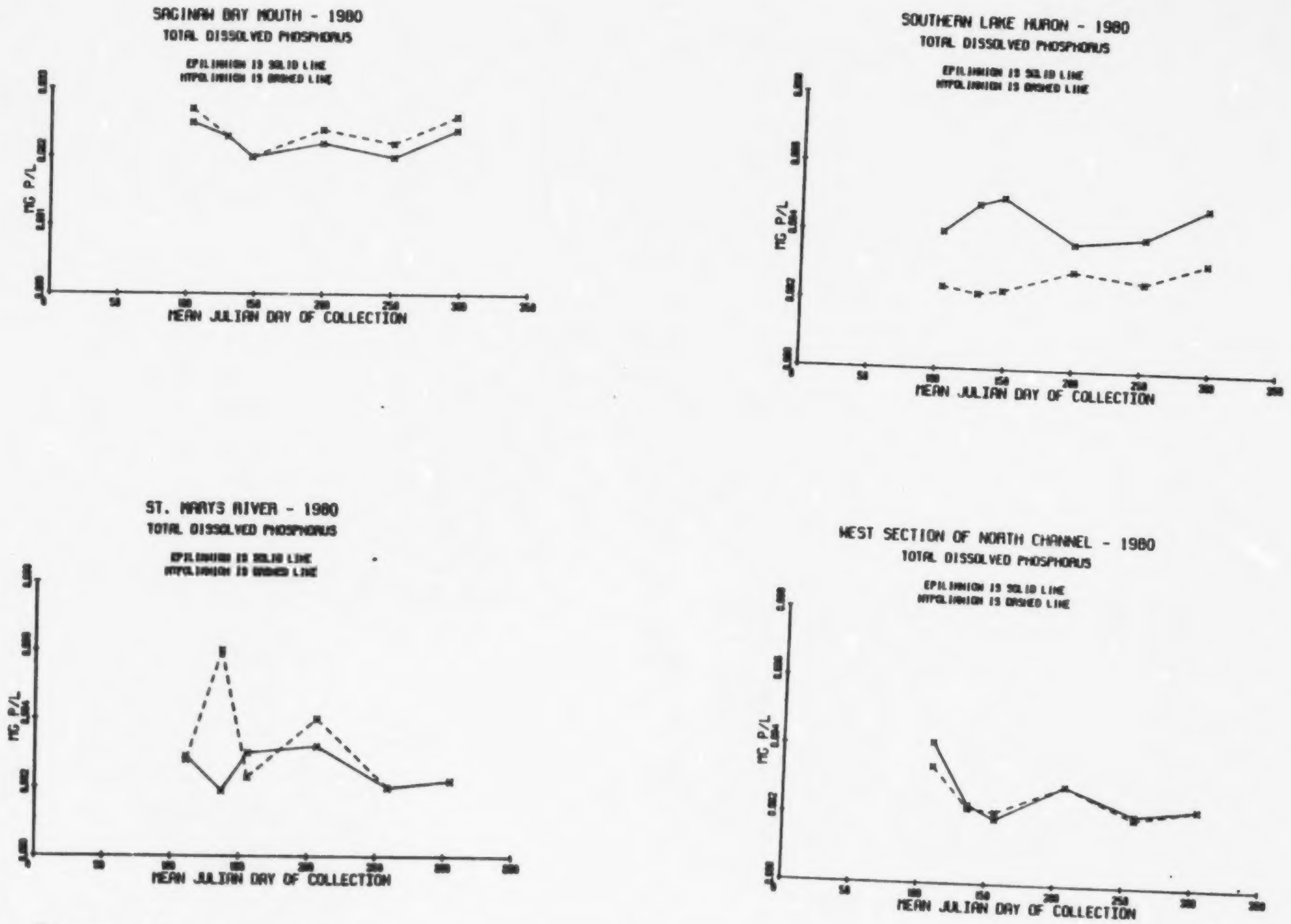
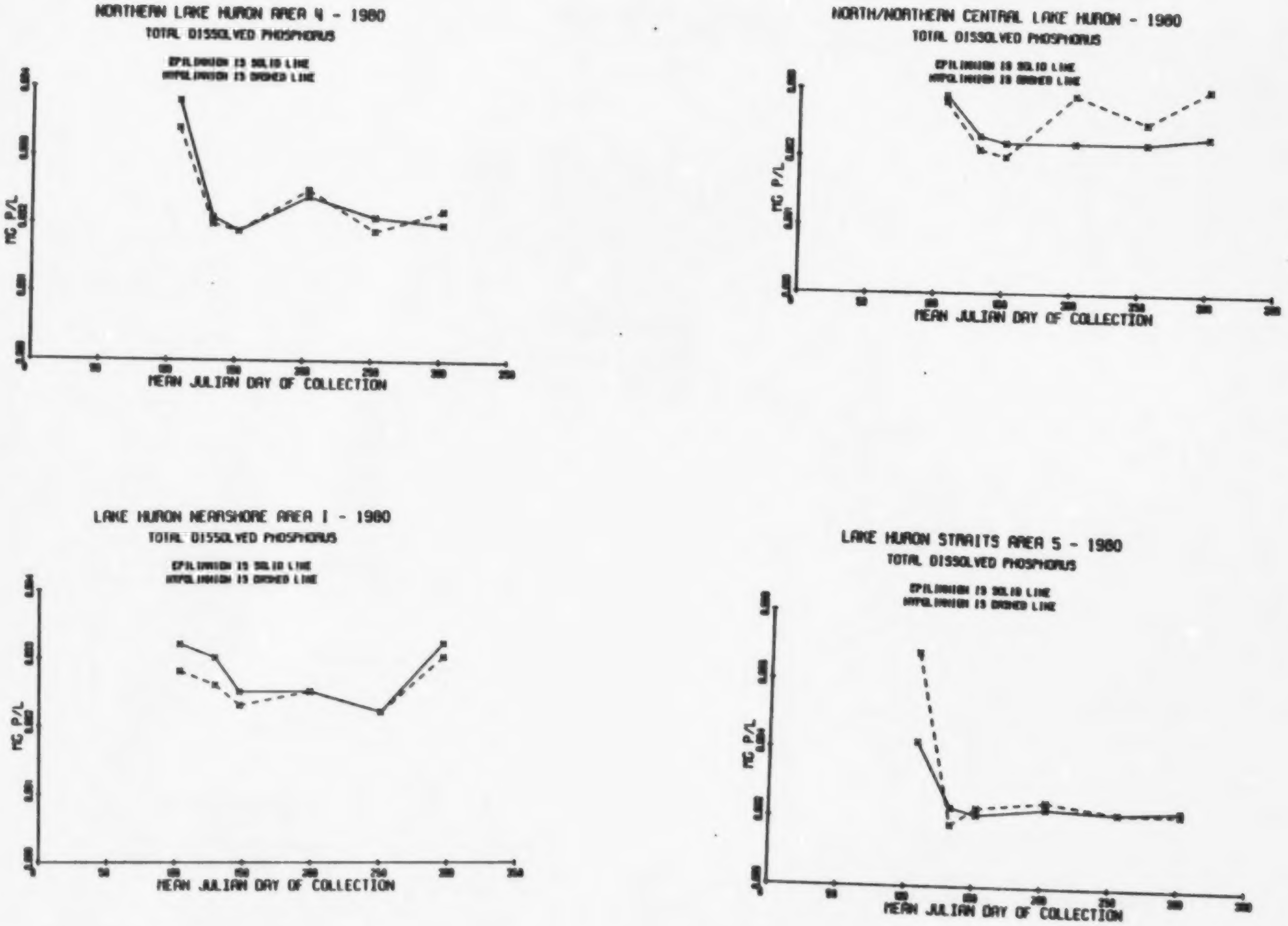


Figure 5.3. Time variation of total dissolved phosphorus during 1980.



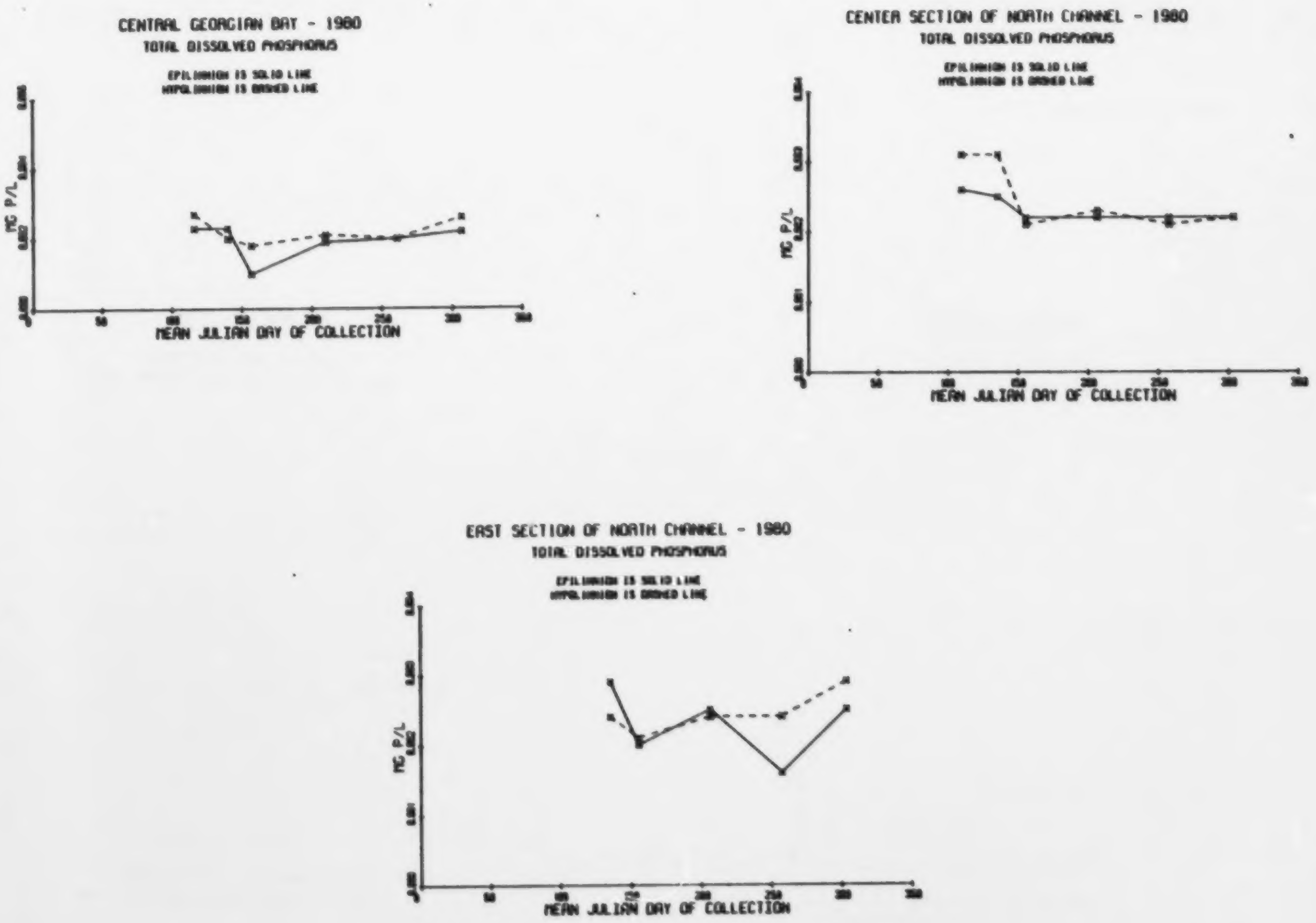
NORTHERN LAKE HURON AREA 4 - 1980
TOTAL DISSOLVED PHOSPHORUS

NORTH/NORTHERN CENTRAL LAKE HURON - 1980
TOTAL DISSOLVED PHOSPHORUS

LAKE HURON NEARSHORE AREA 1 - 1980
TOTAL DISSOLVED PHOSPHORUS

LAKE HURON STRAITS AREA 5 - 1980
TOTAL DISSOLVED PHOSPHORUS

Figure 5.3. (Continued).



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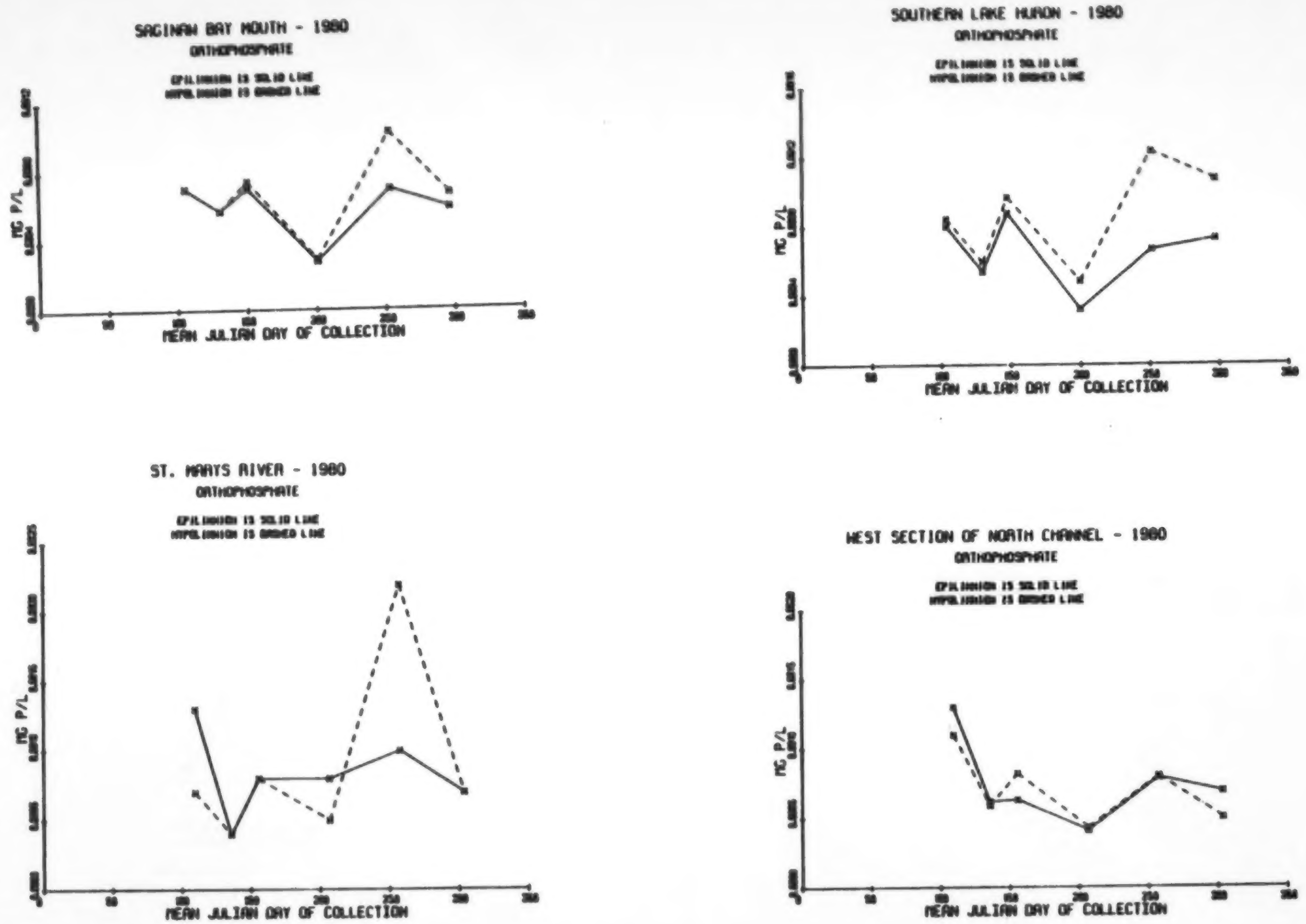


Figure 5.4. Time variation of orthophosphate during 1980.

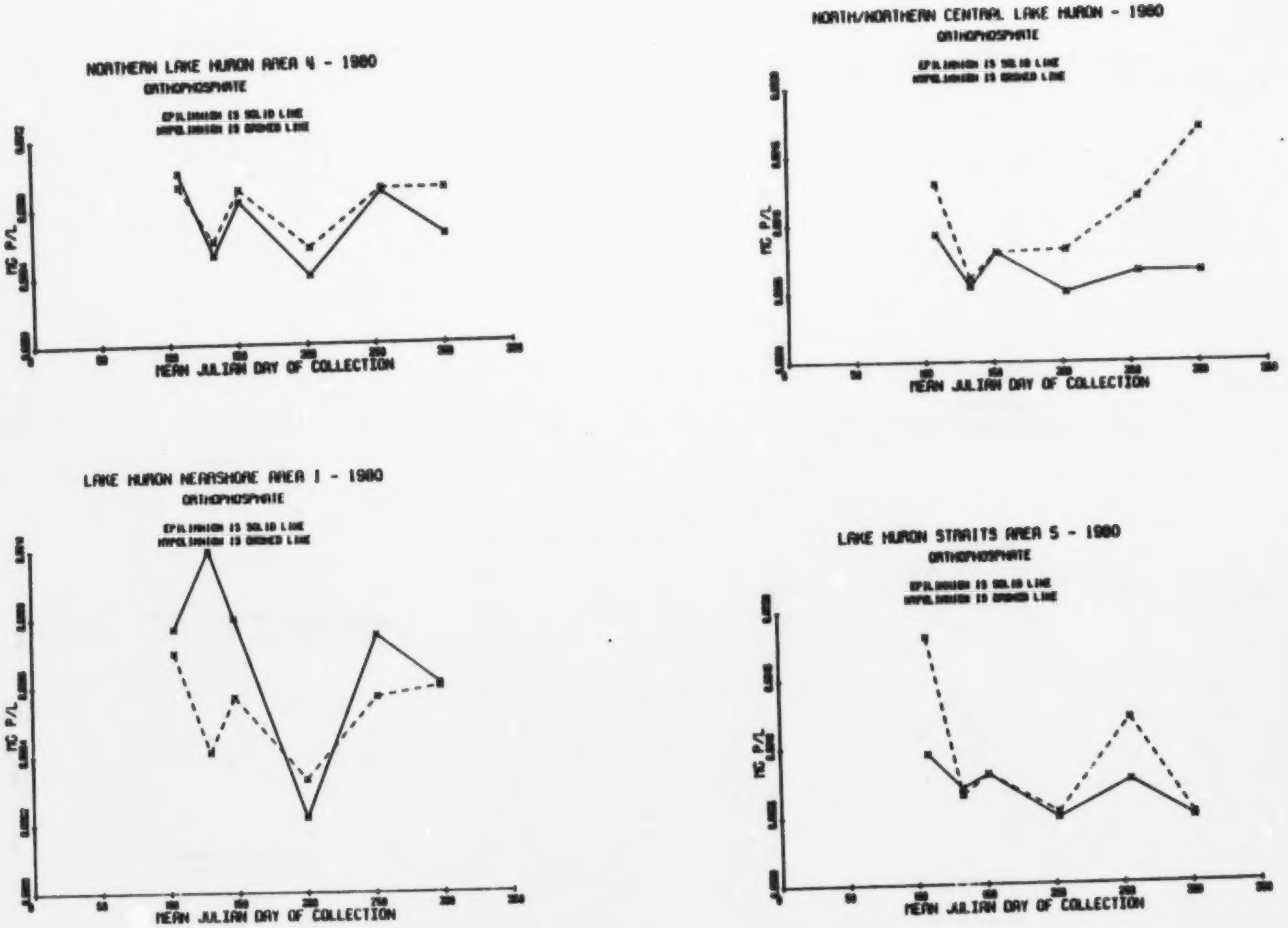


Figure 5.4. (Continued).

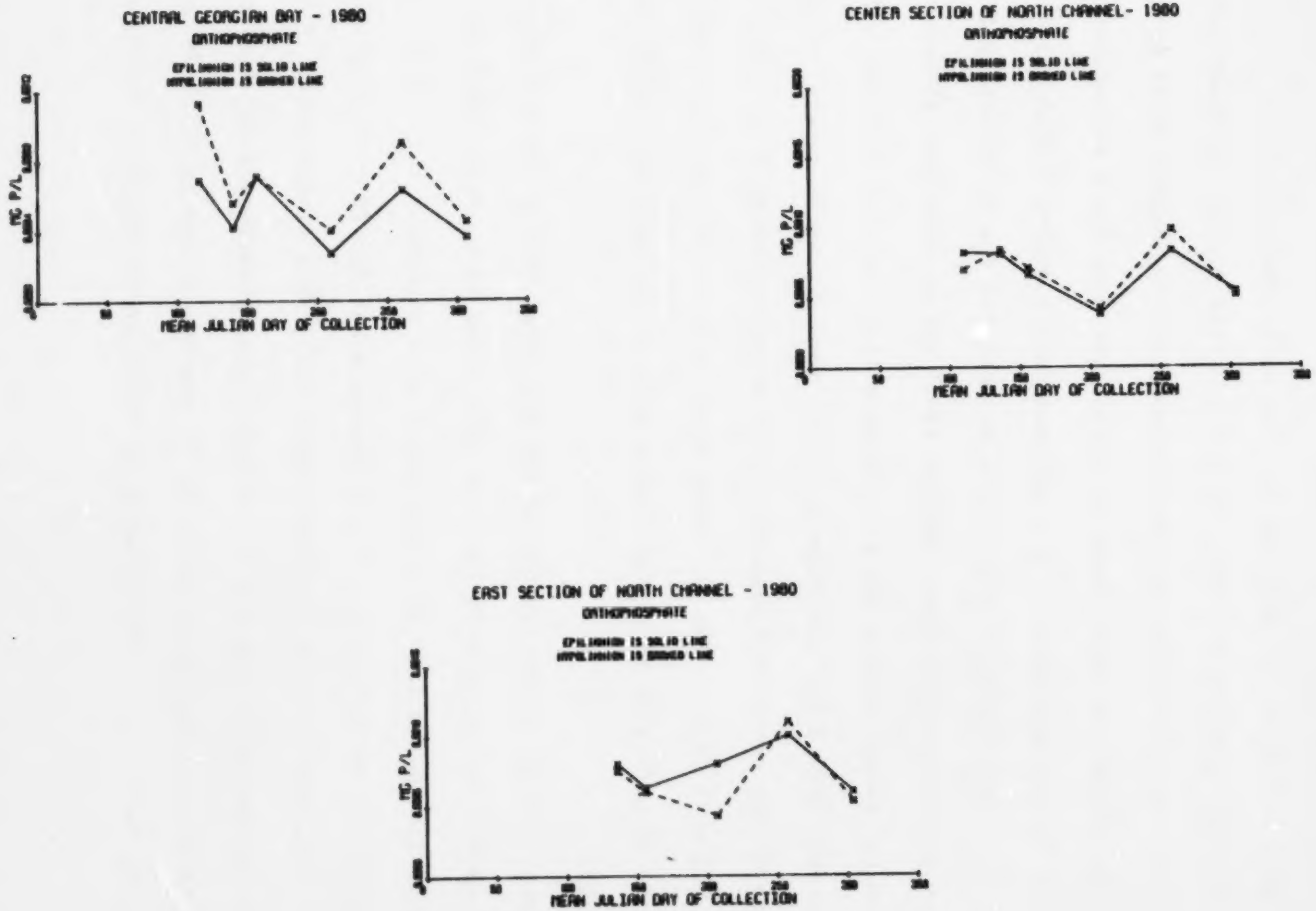


Figure 5.4. (Concluded).

The seasonal ranges of TP, TDP, and SRP concentrations for Lake Huron and North Channel were 2.5-58.1, 1.4-7.6, and 0.1-5.2 μg/L, respectively. For Georgian Bay they were 2.3-15.3, 1.4-6.8, and 0.1-4.0 μg/L, respectively.

The highest observed TP, TDP, and SRP occurred during the first two spring cruises when the water column was homothermous and thoroughly mixed by storms. Although low values for these forms of phosphorus were found throughout the season, SRP values were usually at a minimum during cruise 4 when water temperatures were at their maximum. This would be expected due to orthophosphate being considered the limiting nutrient (Beeton 1969) and to dissolved phosphorus limiting algal growth during the stratified period (Lin and Schelske 1981).

Nearshore area B had the highest annual mean cruise TP concentrations (6.7 μg/L) of all areas with several cruise means exceeding 8 μg/L (8.3 μg/L spring - 8.5 μg/L fall). The St. Marys River station TP concentrations ranged from 6.6 to 10 μg/L with an annual cruise mean of 8.4 μg/L in the S/E samples (Table 5.23).

TP mean cruise concentrations in the S/E layer during the six cruises ranged from 3.5 to 5.1 μg/L in the open lake areas NBLH, SBLH, CBGB, and SBM. Eighteen of the twenty four TP cruise means were between 4 and 5 μg/L and five were between 3.5 and 4.0 μg/L. Annual cruise means for TP concentrations were 4.1, 4.3, 4.5, and 4.7 μg/L for CBGB (Table 5.5), SBLH (Table 5.21), SBM (Table 5.13), and NBLH (Table 5.3), respectively. Statistically significant differences between layers occurred for TP concentrations in 10 of 29 areas (Appendix A, Table A-1). The majority of these events occurred during cruise 4.

In the epilimnion, TP levels in the North Channel ranged from 5.7 to 7.2 μg/L in WNC, 4.0 to 6.6 μg/L in CNC, and 4.7 to 7.5 μg/L in ENC (Tables 5.7, 5.9, and 5.11, respectively). These ranges were similar to those found in 1974 (Warry 1978b).

TP levels in CBGB ranged from 3.1 to 8.1 μg/L in the epilimnion in 1974 (Warry 1978a). The 1980 TP levels in CBGB ranged from 3.5 to 4.5 μg/L (Table 5.5).

TDP and SRP concentrations in the North Channel and Georgian Bay during 1980 had ranges similar to 1974 observations (Warry 1978a,b). Cruise mean TDP concentrations for 1980 were frequently between 2 to 3 μg/L in all areas of the lake and for both the S/E and L/H layers (Tables 5.3-5.24). There were only four occurrences when TDP concentration differences between these layers were statistically significant. These cases occurred in the northern and southern basins of Lake Huron during the stratified period (cruises 4 through 6) (Appendix A, Table A-2).

Seasonal fluctuations were expected for TDP and SRP due to algal utilization (Hutchinson 1957, Beeton 1969, Lin and Schelske 1981). The changes which occurred in TDP and SRP concentrations were not similar to the changes observed for silica and nitrogen. Silica and nitrogen had a single annual minimum. Major reductions in TDP and SRP occurred every other cruise in some areas. The mean TDP maximum depletion was 30% with a 95% confidence interval about the mean from 25 to 35% (Table 5.25). The mean SRP maximum depletion was 56% with the 95% confidence interval about the mean from 51 to 61% (Table 5.25).

SRP mean cruise concentrations seldom exceeded 1 μg/L in Lake Huron, and the majority of these occurrences were during cruises 1 and 5 (Tables 5.3-5.24). The SRP mean layer concentration differences were statistically significant in

Table 5.25. Maximum changes in total dissolved phosphorus and dissolved orthophosphorus cruise mean concentration by area (using 1974 areas; see Fig. 5.1).

Area		TDP (μg/1)					DOP (μg/1)				
1974 Acronym	1980 Acronym	Max	Cr. No.	Min	Cr. No.	1-(MIN/MAX) % Change	Max	Cr. No.	Min	Cr. No.	1-(MIN/MAX) % Change
River	River	3.2	4	2.0	5	38	1.3	1	.40	2	69
A		3.2	3	2.3	5	28	0.85	1	.60	2	29
B		2.7	2	2.1	5	22	0.75	1	.40	4	47
C		2.4	2	1.9	6	21	0.80	3	.48	4	40
D		2.1	2	1.8	6	14	0.77	1	.22	4	71
E		3.0	1	1.9	3	37	0.65	5	.31	6	52
F		4.4	1	1.9	5	57	1.13	1	.34	4	70
G		2.6	2	2.3	2	12	0.80	3	.38	4	52
I	NS-I	3.2	1	2.2	5	31	1.01	2	.22	4	78
1	WNC	3.9	1	1.9	3	51	1.12	1	.41	4	63
2	CNC	2.6	1	2.2	5	18	0.87	1	.38	4	56
3a	ENC	2.5	4	1.6	5	36	1.0	5	.60	6	40
4	A4LH	3.8	1	1.9	3	50	1.0	1	.40	4	60
5	A5LH	4.2	1	2.1	3	50	0.95	1	.48	4-6	49
6	NBLH	2.9	1	2.2	3-5	24	0.93	1	.55	2	41
7	SBM	2.5	1	2.0	5	20	0.63	3	.28	4	56
8	SBLH	2.7	1	2.1	5	22	0.88	3	.32	4	64
9		2.5	2	2.1	4	16	0.80	3	.50	5	38
10		3.0	2	1.7	4	43	1.40	5	.40	6	71
11		2.4	2	1.8	3	25	0.88	1	.32	4	64
12		2.3	1	1.6	3	30	0.77	1	.17	4	78
13		2.3	2	1.8	6	22	0.77	5	.30	6	61
14		2.3	5	2.0	6	13	0.58	3	.28	4	52
15		2.9	2	1.9	5	34	0.70	3	.33	4	53
16		2.5	1	1.9	3	24	0.80	5	.30	6	62
17	CBGB	2.3	1-2	1.9	4	17	0.73	3	.27	4	63
18		3.6	1	1.8	4	50	0.70	1	.30	4	57
3		2.4	2	1.8	3	25	0.78	5	.44	6	44
						Ave 30 ± 05					Ave 56 ± 05

areas A5LH, NBLH, SBM, SBLH, and CBGB, as well as area 9, area 11, and area 13 during cruises 5 and 6 (Appendix A, Tables A-15 - A-30).

The majority of maximum SRP and TDP mean cruise concentrations were observed during cruise 1. These levels reflect the nutrient concentrations prior to the early spring phytoplankton bloom. TDP mean cruise concentrations were highest in A4LH (3.8 μg/L), A5LH (4.2 μg/L), WNC (3.9 μg/L), and nearshore area F (4.4 μg/L). These areas were sampled shortly after ice-out conditions during cruise 1. Numerous small icebergs and floes were encountered in A4LH, A5LH, WNC, and nearshore area F.

Dissolved Reactive Silica -- Dissolved reactive silica (DRS) concentrations reflect seasonal uptake of this nutrient which is important for diatoms and silica flagellates to form their cell walls (Schelske and Stoermer 1971).

Spring areal mean cruise DRS concentrations are summarized for the St. Marys River, North Channel, Georgian Bay, and Lake Huron. In the St. Marys River, station 69, the spring S/E layer's DRS concentration was 2.23 mg/L reflecting high DRS concentration of Lake Superior waters (Schelske and Roth 1973). In 1980, in the North Channel nearshore, area F, the maximum spring areal mean cruise DRS concentration was 2.2 mg/L (Table 5.26). In 1974, high epilimnetic DRS concentrations were also found in the North Channel and ranged from 2.04 to 2.46 mg/L (Warry 1978b). Georgian Bay spring DRS areal mean cruise concentrations ranged from 1.2 to 1.6 mg/L with the highest levels found along the northern shoreline (area 18) and the lowest along the southern shoreline (area D). Typical Georgian Bay open lake areas had spring DRS areal mean cruise concentrations around 1.2 mg/L (areas 13 and 16). CBGB had spring DRS areal mean cruise concentrations of 1.2 mg/L in 1980 (Table 5.5). In 1974, Warry

Table 5.26. Maximum depletion of surface/epilimnetic dissolved reactive silica concentrations by area.

Areas		1 Spring Cr. Maximum		2 Summer Cr. Minimum		3	4
1974 Acronym	1980 Acronym	mg/L	Cr. No.	mg/L	Cr. No.	Maximum % Depletion	Absolute Difference Columns 1-2 (mg/L)
River	River	2.21	1	2.10	3	5	.11
A		1.44	1	0.665	4	54	.78
B		1.45	1	0.733	4	49	.72
C		1.40	1	0.890	4	36	.51
D		1.21	1	0.906	4	25	.30
E		1.53	1	0.834	4	45	.70
F		2.22	2	1.51	5	32	.71
G		1.50	3	.673	5	55	.83
I	NS-I	1.22	1	.760	3	38	.46
1	WNC	2.09	1	1.70	5	19	.39
2	CNC	2.12	2	1.49	5	30	.63
3a	ENC	1.78	2	1.43	4	20	.35
4	A4LH	1.75	3	.907	4	48	.84
5	A5LH	1.50	3	.644	4	43	.86
6	NBLH	1.55	1	.898	5	42	.65
7	SBM	1.53	2	.892	5	42	.42
8	SBLH	1.50	1	.889	5	41	.61
9		1.50	3	.913	4	39	.59
10		1.22	2	.960	4	21	.26
11		1.23	1	.913	4	26	.32
12		1.23	1	.893	5	27	.34
13		1.18	1	.873	5	26	.31
14		1.22	1	.820	5	33	.40
15		1.51	2	.792	4	48	.72
16		1.18	1	.736	4	38	.44
17	GBGB	1.23	1	.846	5	31	.38
18		1.67	1	.881	4	47	.79
3		1.39	1	1.00	4	28	.39
						Ave 35 ± 2	

(1978a) observed 1.4 mg/L spring DRS concentrations in CBGB in 1974. In 1980, Lake Huron spring DRS areal mean cruise concentrations ranged from 1.5 to 1.6 mg/L in NBLH and SBLH. Nearshore spring DRS areal mean cruise concentrations in Lake Huron were similar in magnitude to the concentrations of adjacent open lake areas.

Seasonal variation in DRS is often taken as a measure of nutrient utilization (Schelske and Roth 1973). The amount of depletion of DRS was estimated by comparing the maximum observed spring areal cruise mean of the S/E samples with the minimum observed summer areal cruise mean (Table 5.26). This measure of depletion is valid only in those open lake areas which are unaffected by upwelling and located beyond the influence of DRS point sources such as tributaries and other large lakes. The resulting average depletion in all areas was 35 ± 2% with an average absolute depletion of 0.53 ± 0.04 mg SiO_2/L.

The general pattern in many of the geographical areas was DRS concentration depletion in the epilimnion and DRS concentration increases in the hypolimnion (Fig. 5.5). The DRS concentrations in the S/E and L/H layers are illustrated in Chapter 4, Figure 4.14. Six vertical (NBLH, SBLH, SBM, CBCG, A4LH, and A5LH) DRS traces show decreasing S/E concentrations during the early cruises followed by gradually increasing S/E concentrations during cruises 5 and/or 6. This resulted from a deepening of the epilimnion which mixed with hypolimnetic waters. The difference in concentrations between these layers became statistically significant during cruises 4 and 5 in almost all areas (Appendix A, Table A-4). For most areas, statistically significant differences between S/E and L/H occurred during thermal stratification except for two cases.

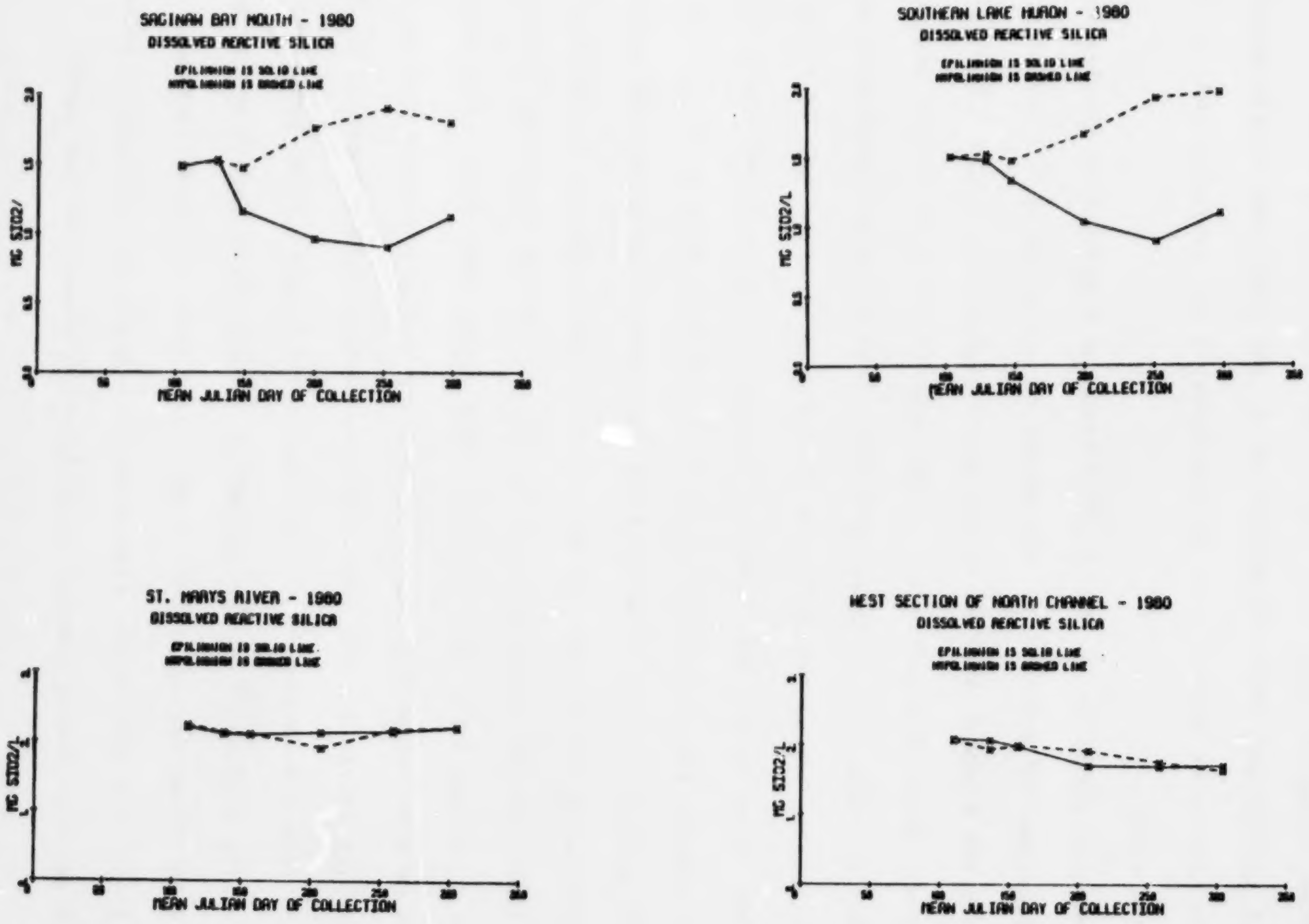
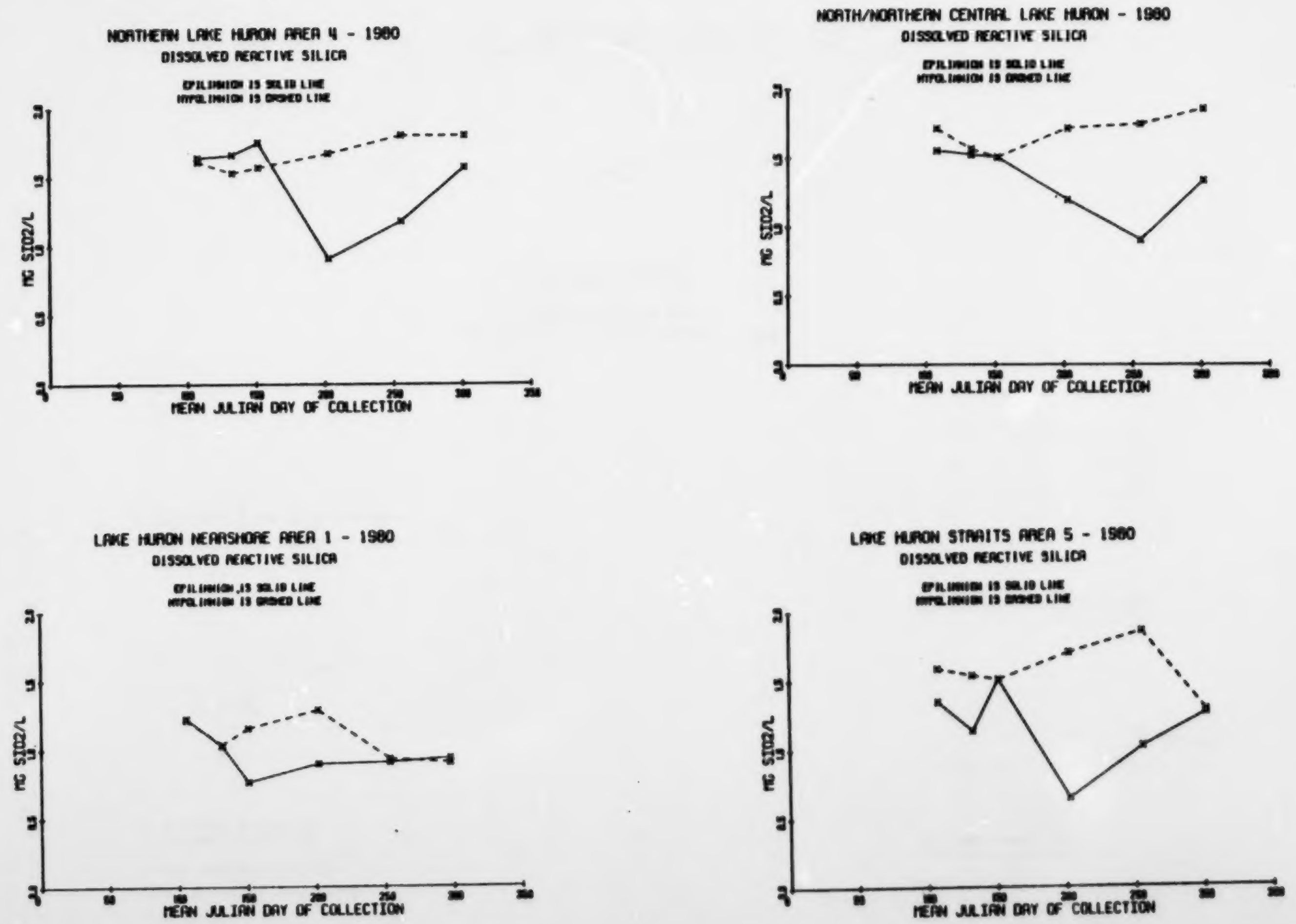


Figure 5.5. Time variation of dissolved reactive silica during 1980.

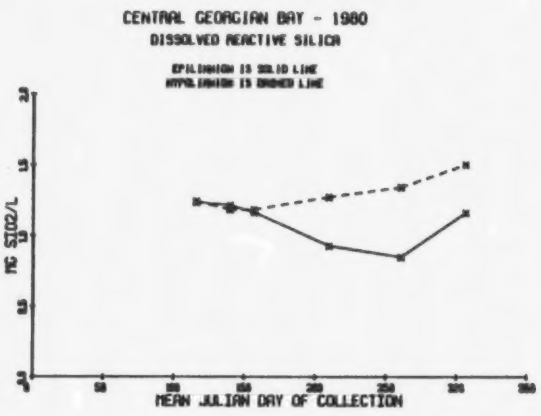

NORTHERN LAKE HURON AREA 4 - 1980
DISSOLVED REACTIVE SILICA

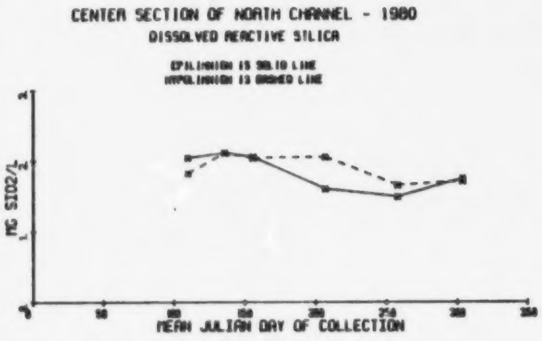
NORTH/NORTHERN CENTRAL LAKE HURON - 1980
DISSOLVED REACTIVE SILICA

LAKE HURON NEARSHORE AREA 1 - 1980
DISSOLVED REACTIVE SILICA

LAKE HURON STRAITS AREA 5 - 1980
DISSOLVED REACTIVE SILICA

Figure 5.5. (Continued).





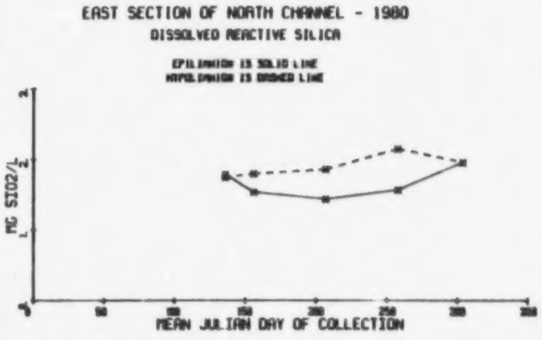


Figure 5.5. (Concluded).

The St. Marys River, station 69, had no observed depletion of DRS in the S/E waters. The WNC area showed the second smallest depletion (19%) of all the areas (Table 5.26). The WNC, like the St. Marys River station, received water from Lake Superior and did not show a large seasonal change. There was only one cruise where the DRS concentration differences between the epilimnion and the hypolimnion exceeded .3 mg/L even though the water column is relatively deep (58 m maximum depth).

In the areas where statistically significant differences in DRS concentrations between the limnions were not noted, seasonal DRS depletion occurred. These depletions were as large as .6 mg/L in absolute magnitude, or a 55% depletion. Several reasons for the lack of statistical significance, in spite of the magnitude of the DRS differences, were the high variability of the observed DRS concentrations (areas 3 and 18), the shallow water column (nearshore areas A, B, and G), or a DRS concentration depletion in the entire water column between cruises (WNC).

Station 78 showed complete depletion of DRS in the entire water column. This station represented most of the North Channel in 1980 (WNC and ENC). At this station, summer DRS concentrations decreased and did not return to the spring DRS concentrations by the sixth cruise (beginning of the fall overturn conditions). The DRS concentration at station 78 declined from 2.16 mg/L (cruise 1) to 1.61 mg/L (cruise 6). This complete depletion pattern was seen in areas of WNC, CNC, and nearshore areas C and I. In these areas, spring DRS concentrations cannot be restored by simply mixing in the hypolimnetic waters as in the deep water lake areas. Only by a resupply of DRS from the St. Marys River can this area be restored to spring DRS levels. Nearshore areas C and I can be resupplied when the offshore waters are mixed into the nearshore zones during the winter period.

Nitrate plus Nitrite — Dissolved nitrate + nitrite (DNN) concentrations decreased in the S/E layer as the water temperature increased (Fig. 5.6). The difference between the observed spring maximum concentration and the observed summer minimum concentration in the S/E layer is an indication of the utilization of the DNN, or nutrient depletion (Schelske 1975). Differences between S/E and L/H DNN concentrations were almost always statistically significant during stratified conditions in all areas of Lake Huron, Georgian Bay, and the North Channel (Appendix A, Table A-5). The L/H layer DNN concentrations were generally greater than those found in the S/E layer. This can be due to the algal uptake of DNN in the epilimnion where algal activity is enhanced in the photic zone (Hutchinson 1957, Wetzel 1975).

Maximum DNN depletions observed in 1980 are shown in Table 5.27 for all areas. The comparison was made between the highest observed DNN concentration in the nearshore of 283 ± 17 g/L and open lake of 276 ± 10 g/L (usually cruise 1) with the lowest observed DNN concentration in all areas of 226 ± 4 g/L (which most frequently was observed on cruise 4). Maximum percent depletion in nearshore areas of DNN averaged 19.6% (95% C.I. = ±4.2%) with areas A and B removed. There was an apparent source of DNN in nearshore areas A and B. These two areas had the highest spring concentrations in 1980. Elevated levels persisted from cruise 1 to cruise 3. In these areas, maximum DNN concentrations were found (station 11 - cruise 1 - 485 g/L, station 4 - cruise 2 - 735 g/L, and station 3 - cruise 3 - 765 g/L). Maximum percent depletion in open lake areas averaged 18.9% (95% C.I. = ±2.7%).

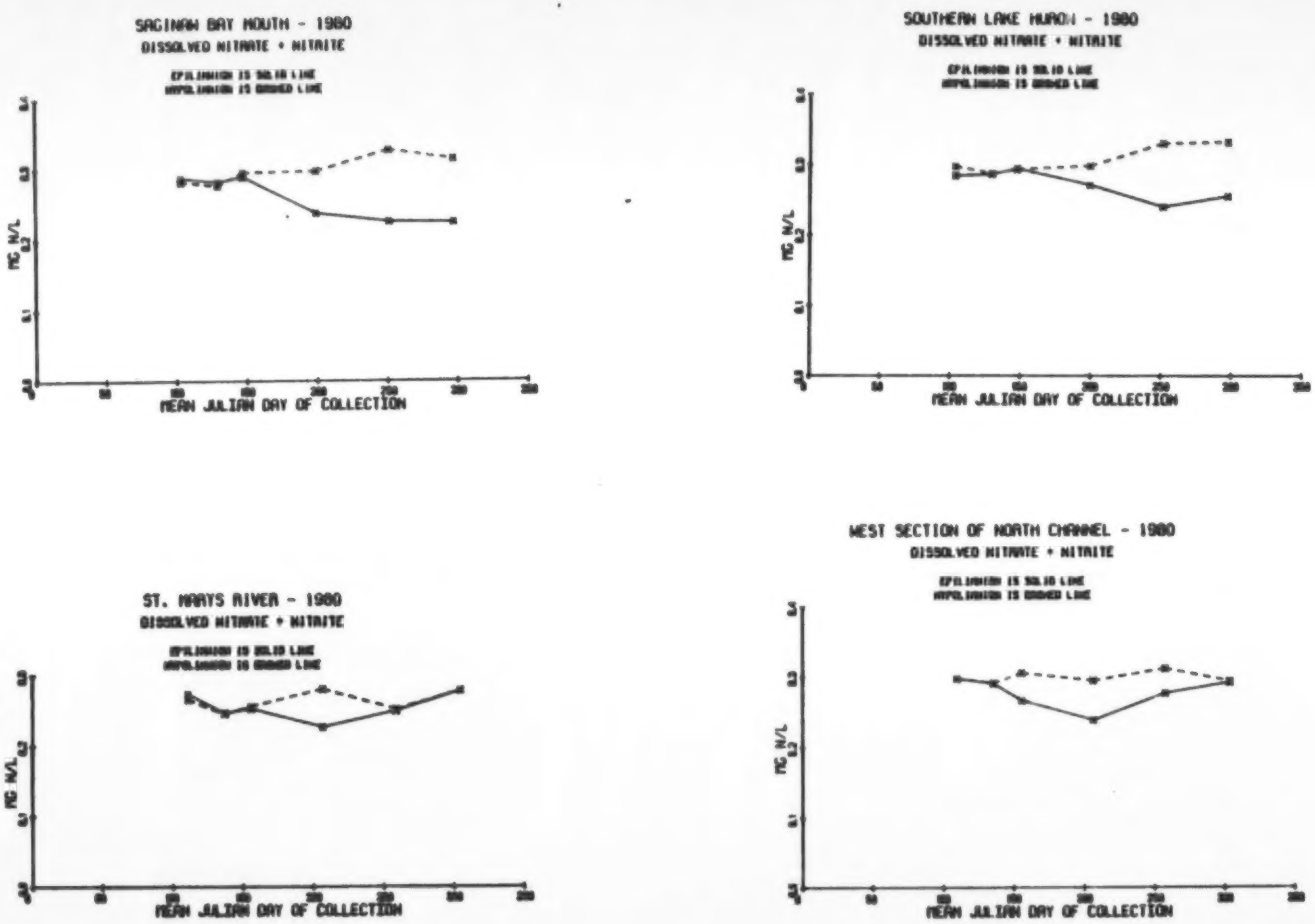


Figure 5.6. Time variation of dissolved nitrate plus nitrite during 1980.

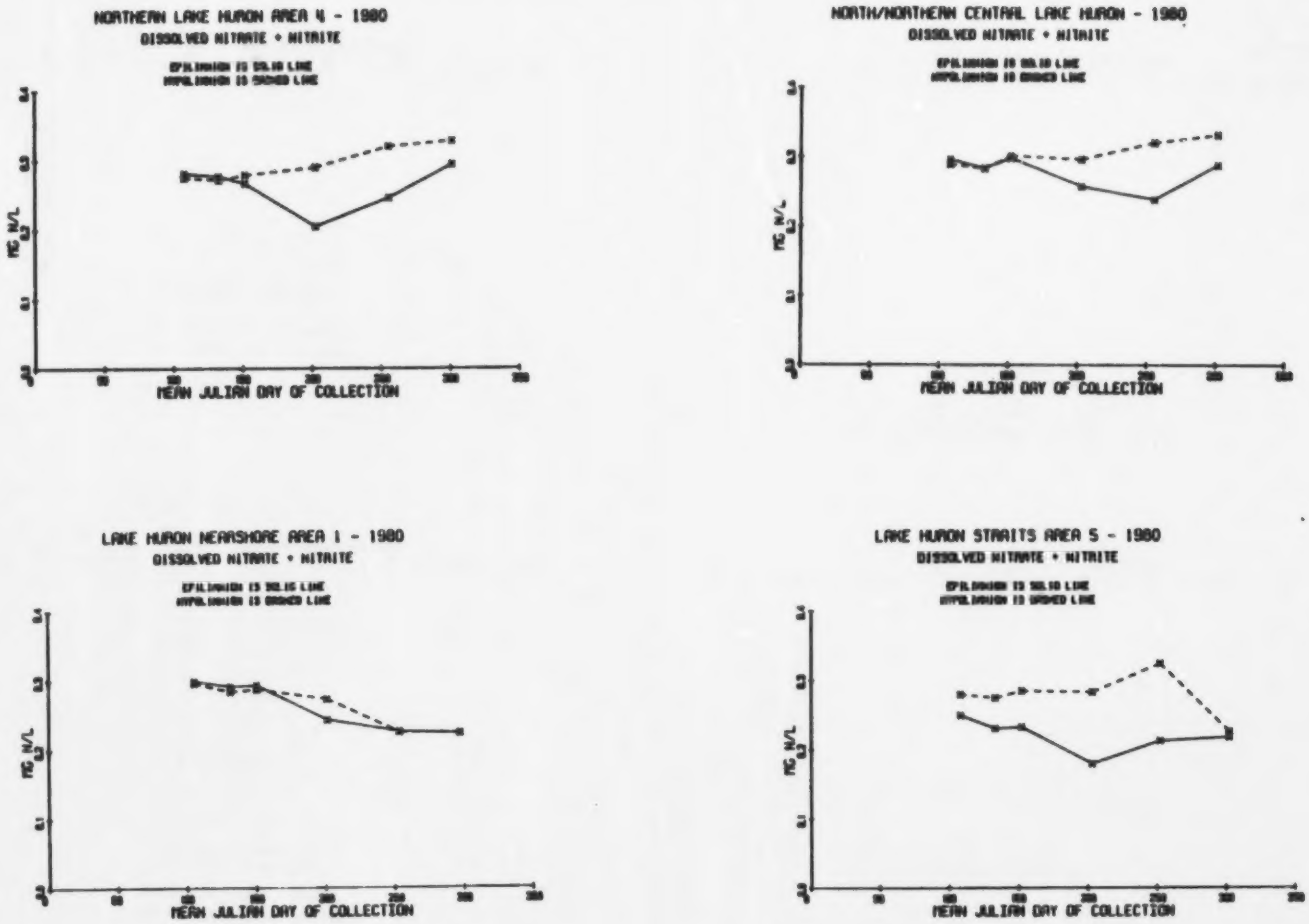


Figure 5.6. (Continued).

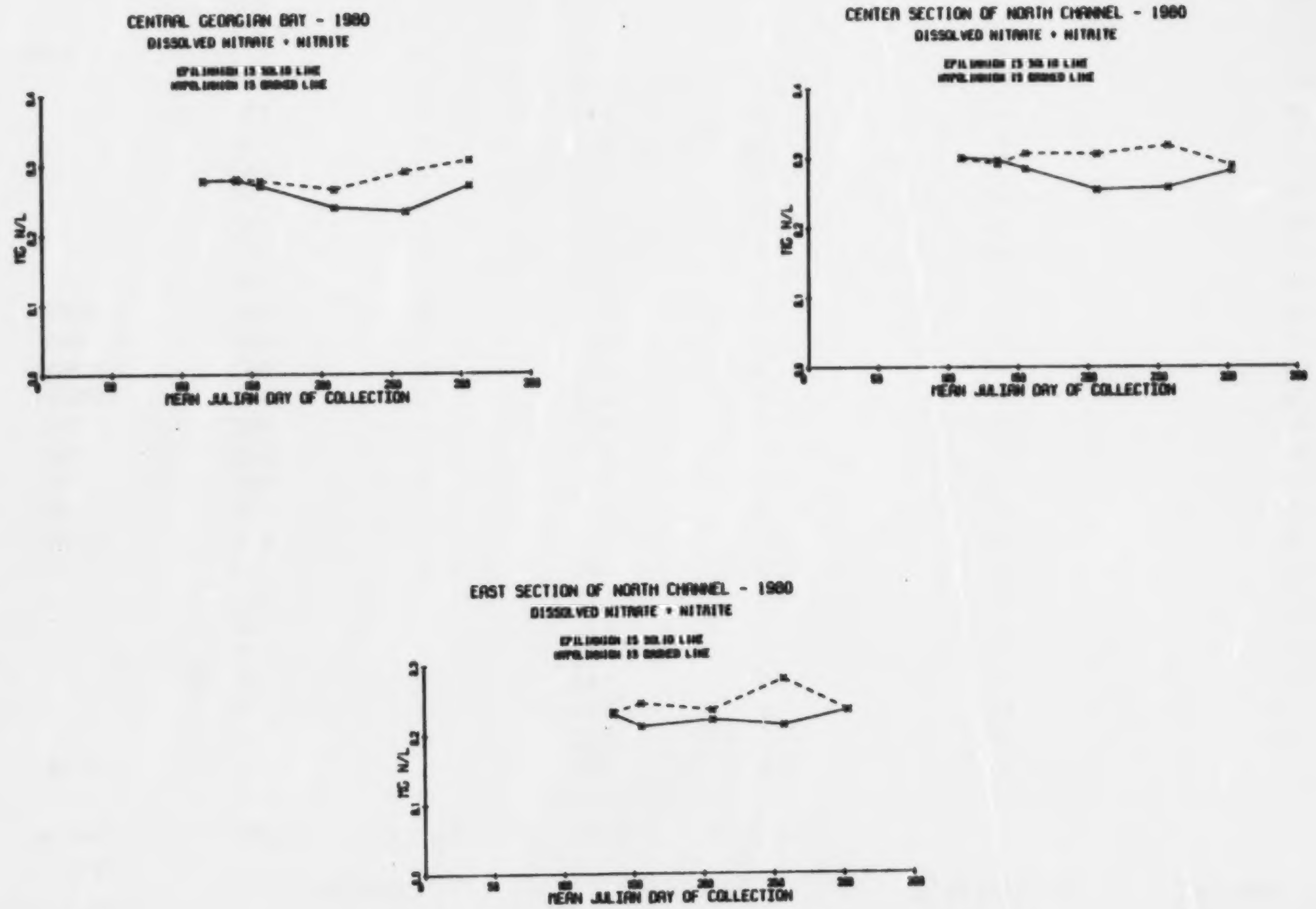


Figure 5.6. (Concluded).

Table 5.27. Maximum depletion of surface/epilimnetic dissolved nitrate + nitrite concentrations by area (μg/L).

Areas 1974-80		1 Spring Cruise Maximum		2 Summer Cruise Minimum		3 Maximum % Depletion	4 Absolute Difference Columns 1-2 (μg/L)
1974 Acronym	1980 Acronym	μg/L	Cr. No.	μg/L	Cr. No.		
River	River	273	1	226	4	17	47
A		522	3	240	5	54	282
B		478	2	243	5	49	235
C		299	1	248	6	17	51
D		282	2	241	5	15	41
E		256	1	212	4	17	44
F		301	1	243	4	19	58
G		270	1	203	5	25	67
I	NS-I	303	1	222	6	27	81
1	WNC	296	1	237	4	20	59
2	CNC	300	1	254	4	15	46
3	ENC	229	2	211	3	8	18
4	A4LH	280	1	204	4	27	76
5	A5LH	249	1	179	4	28	70
6	NBLH	298	3	238	5	20	60
7	SBM	289	3	229	5	21	60
8	SBLH	294	3	240	5	18	54
9		283	3	247	4	13	36
10		288	2	207	4	28	81
11		282	2	243	5	14	39
12		283	2	241	5	15	42
13		282	2	238	5	16	44
14		283	1	232	5	18	51
15		274	1	217	4	21	57
16		271	1	208	4	23	63
17	CBGB	277	1	232	5	16	45
18		243	1	215	4	12	28
3a		240	1	178	4	26	62
All Areas		Avg 294 ± 12		Avg 226 ± 4		Avg 21 ± 2	Avg 68 ± 11
All Areas Except A&B		Avg 278 ± 4		Avg 225 ± 4		Avg 19 ± 1	Avg 53 ± 3

In 1974, Warry (1978a) reported a CBGB areal epilimnetic maximum DNN concentration of 260 μg/L. This compares to a 277 μg/L DNN concentration in 1980. For a North Channel epilimnetic spring maximum, Warry (1978b) reported DNN concentrations of 300 μg/L (WNC), 270 μg/L (CNC), and 280 μg/L (ENC). These compare with 296 μg/L (WNC), 300 μg/L (CNC), and 229 μg/L (ENC) in 1980.

Ammonia — Relatively stable and homogeneous dissolved ammonia (DA) concentrations were observed throughout the water column in NBLH and SBLH during the first and second cruises (Tables 5.3-5.24, Fig. 5.7). Samples from these two areas ranged from 1.6 to 2.2 μg/L for cruises 1 and 2. Differences in DA concentrations between S/E and L/H layers became statistically significant during cruise 4 (Appendix A, Table A-6) in 14 of the 27 areas. The concentrations observed in areal hypolimnetic DA were two to four times the observed epilimnion DA concentrations found in each area during cruise 3 and/or 4. Maximum DA concentrations in the hypolimnetic layer ranged from 6.6 μg/L CR3-CNC to 11.4 μg/L CR4-SBLH, with six areas between 9-12 μg/L (ENC, SBM, SBLH, area 12, area 15, and CBGB). Warry (1978a) reported higher hypolimnetic DA concentrations in the North Channel, ranging from 15-16 μg/L in CNC and ENC in June. In these areas, the hypolimnetic DA concentrations found in June were two to five times those of other cruises (Fig. 5.7).

Higher DA concentrations were observed for cruises 3 and 4 in most of the hypolimnetic traces for these areas. North Channel DA concentrations in WNC were high during cruise 1 (>12 μg/L). Warry (1978a) reported levels as high as 24.9 to 32.3 μg/L during May in WNC. Nearshore area A was the only place where DA concentrations exceeded those found in WNC (15.5 μg/L - cruise 4 hypolimnion).

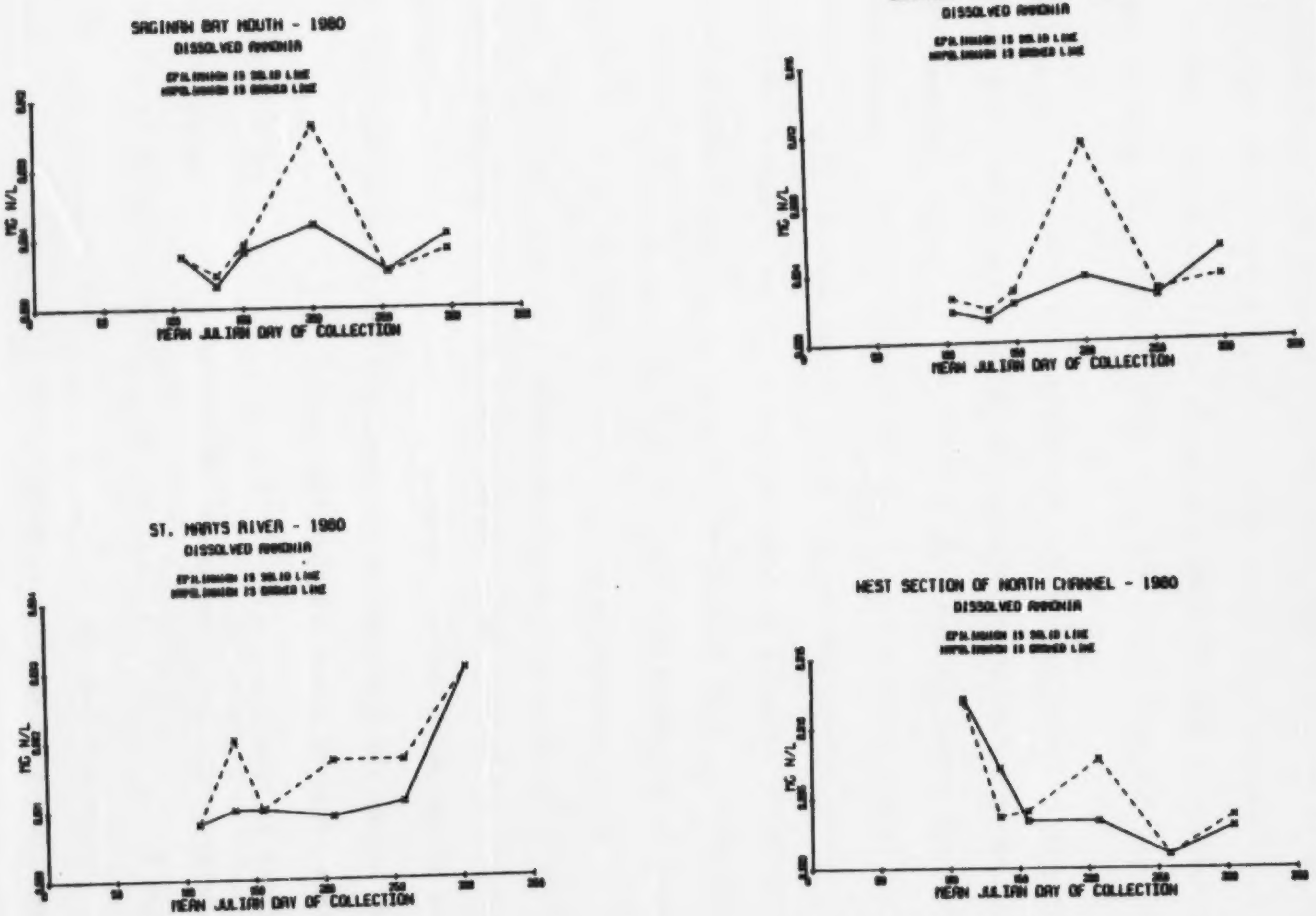


Figure 5.7. Time variation of dissolved ammonia during 1980.

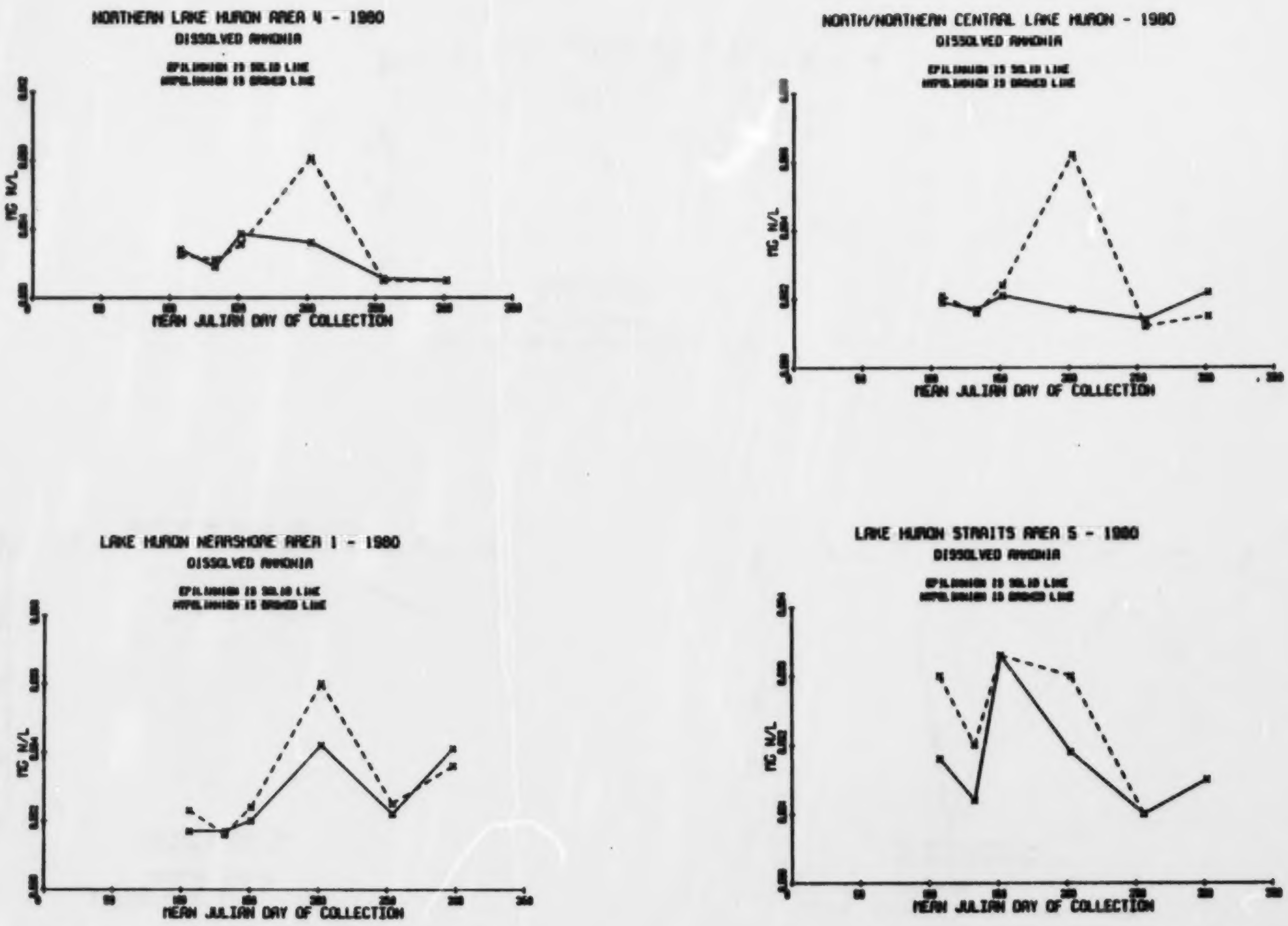


Figure 5.7. (Continued).

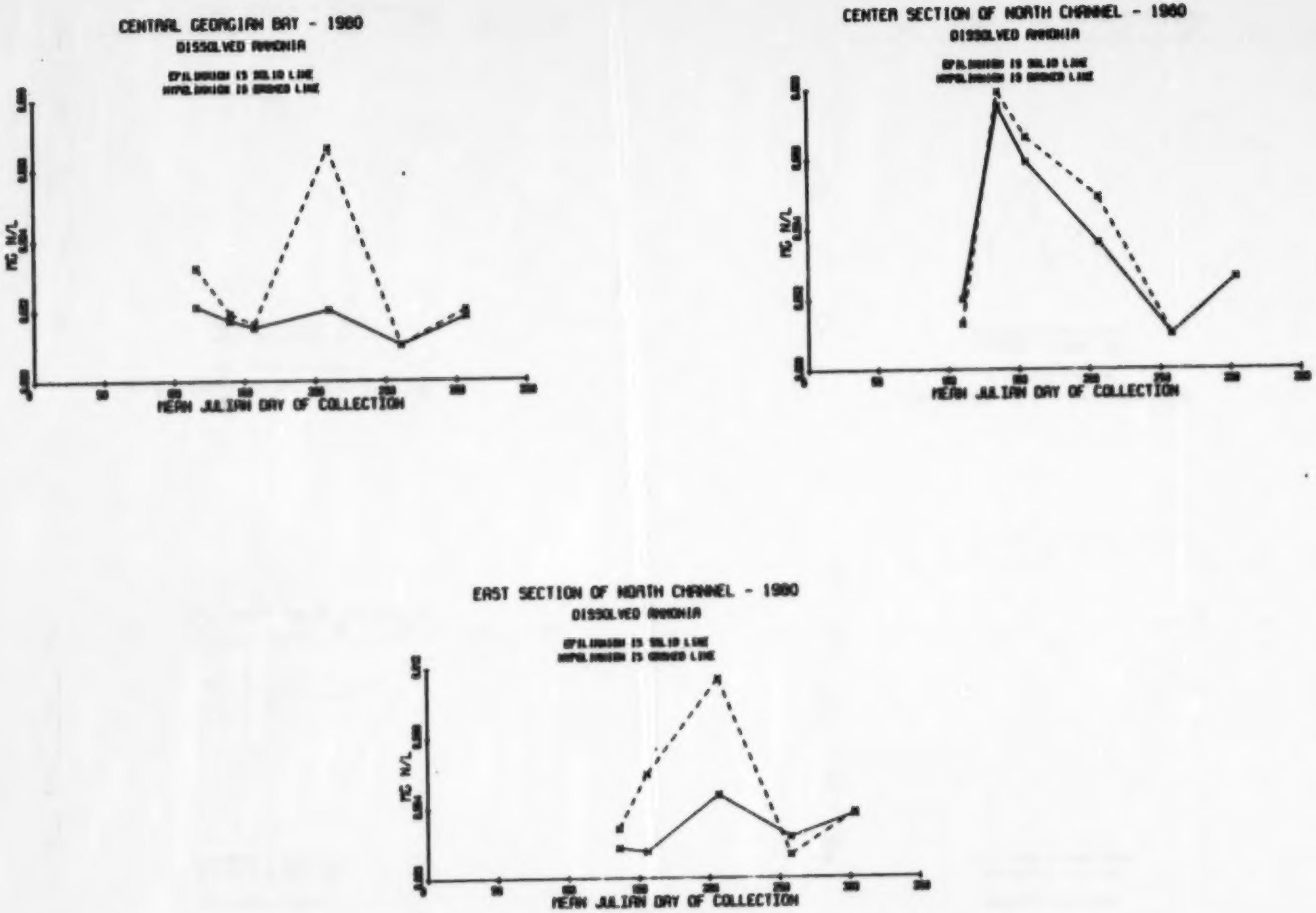


Figure 5.7. (Concluded).

In CNC (cruise 4), SBM (cruise 5), SBLH (cruise 5), and open lake area 13 (cruise 5) the areal DA concentrations for the metalimnion showed increased levels when compared to the epilimnion and hypolimnion. This DA pattern was also found in Lake Michigan's southern basin in 1976 and 1977 (Rockwell et al. 1980). Increased DA concentrations are often attributed to increased zooplankton excretion or dieoff and decay of algal forms (Evans 1983).

Specific Conductivity -- In 1974, specific conductances ranging from 133 to 191 μmho/cm in WNC, 155 to 198 μmho/cm in CNC, and 164 to 181 μmho/cm in ENC were reported by Warry (1978a). In 1980 the corresponding ranges were 125.9 to 178 μmho/cm in WNC, 155 to 194.8 μmho/cm in CNC, and 157.7 to 172.6 μmho/cm in ENC (Tables 5.3-5.24).

In 1974, specific conductances ranging from 182 to 194 μmho/cm in CBGB epilimnetic layer were reported by Warry (1978b). In 1980 the corresponding ranges in CBGB were 178.8 to 193.7 μmho/cm (Tables 5.3-5.24).

Statistically significant conductivity differences between S/E and L/H layers developed during most of the stratified cruises even though this variable is not expected to be influenced by temperature or biota (Fig. 5.8) (Hutchinson 1957, Wetzel 1975). In addition, no observations of calcium carbonate precipitation, "milky waters," were reported. Cruise 4 had sixteen of the twenty seven areas showing statistically significant differences (Appendix A, Table A-7).

Chloride and Sulfate -- During 1980, chloride and sulfate concentrations in Lake Huron had spatial distributions which were similar to the specific conductance distribution. In the St. Marys River, chloride concentrations ranged from 1.4 to 6.3 mg/L and sulfate concentrations ranged from 3.2 to 16.7 mg/L.

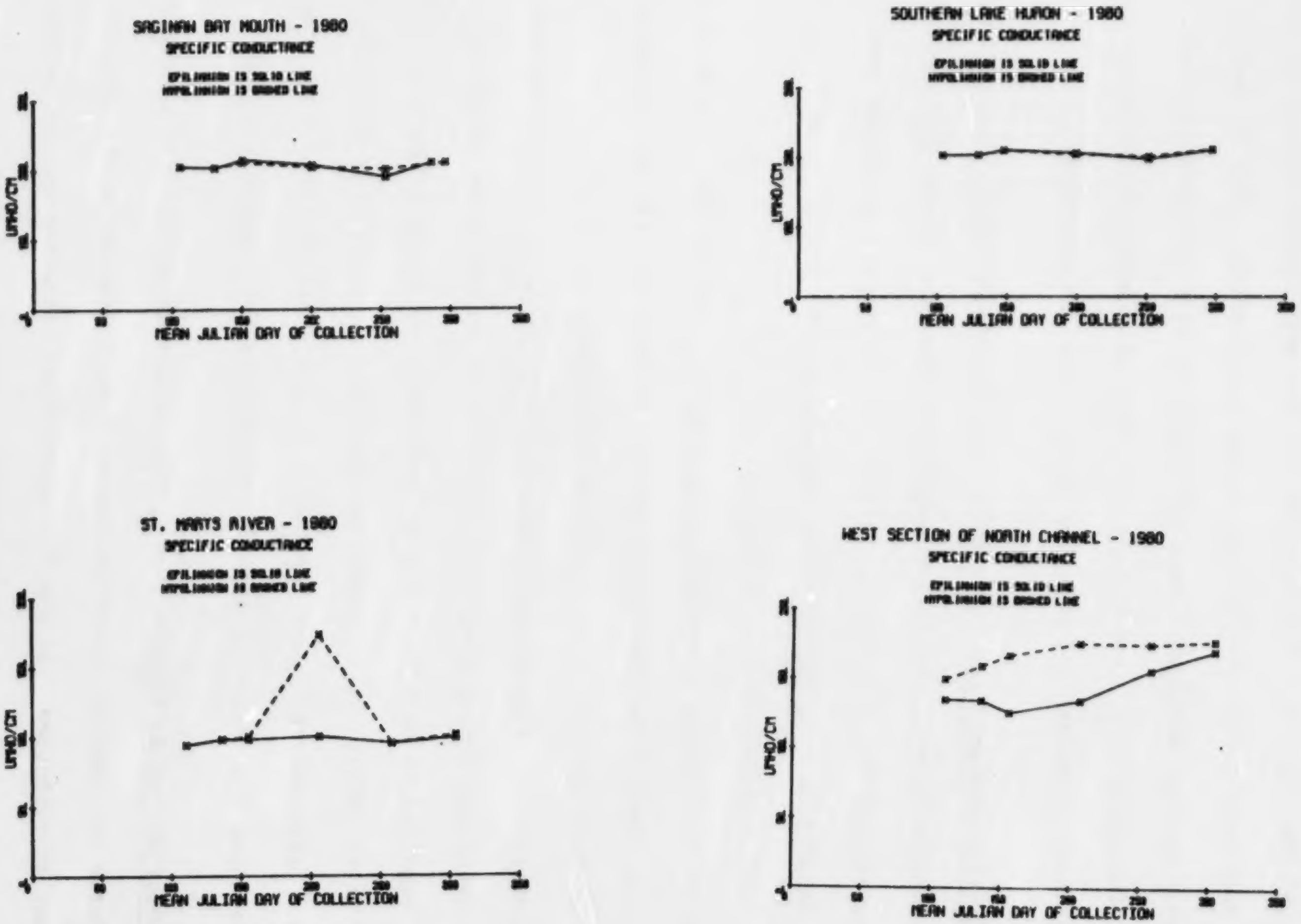


Figure 5.8. Time variation of specific conductance during 1980.

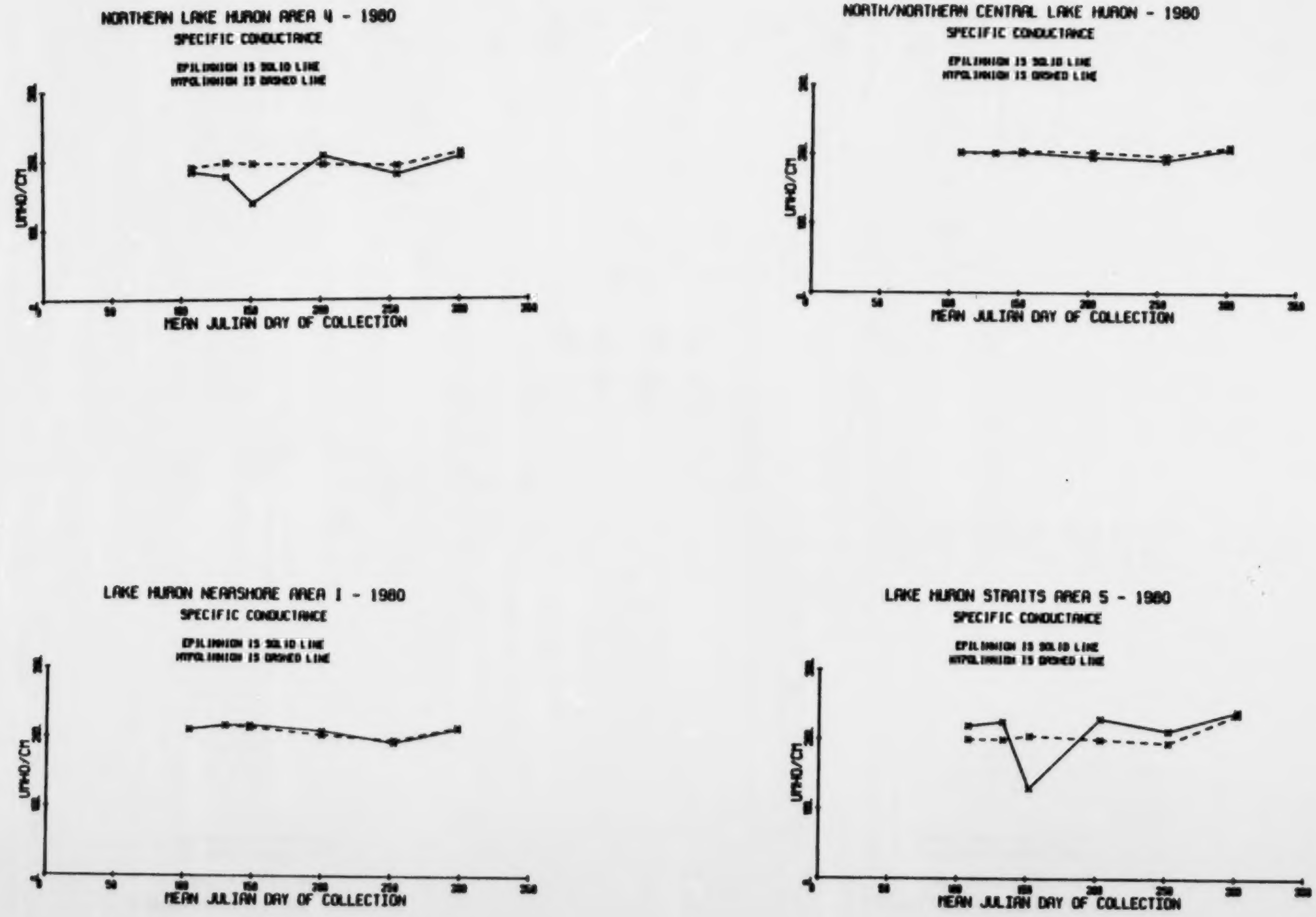
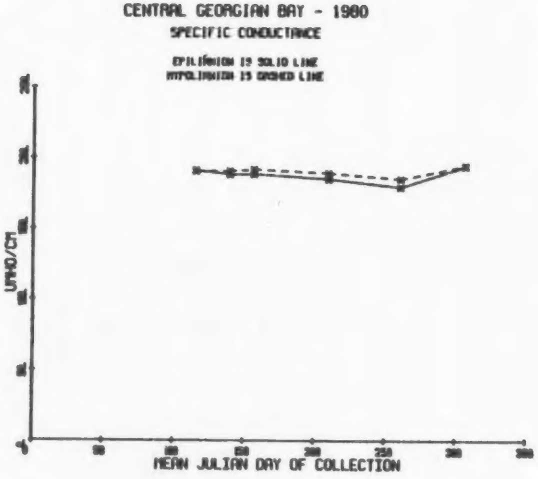
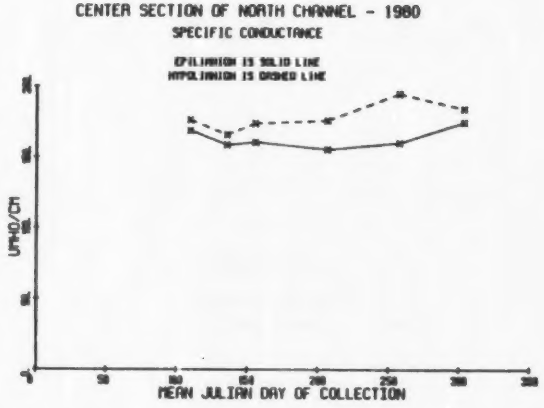


Figure 5.8. (Continued).





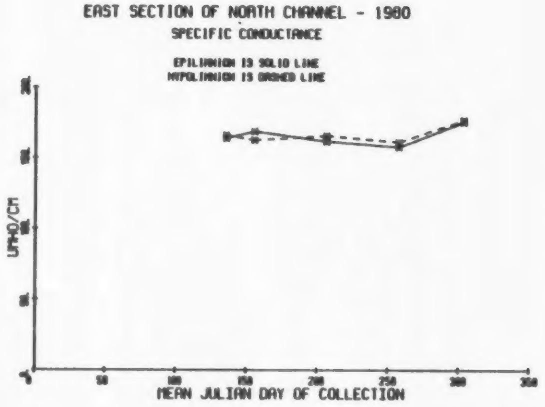


Figure 5.8. (Concluded).

Annual average A5LH chloride and sulfate concentrations were 6.3 mg/L and 15.7 mg/L in the S/E layer and 5.8 mg/L and 15.7 mg/L in the L/H layer, respectively (Tables 5.19-5.20). These values represent a mixing of higher concentration Lake Michigan waters (7.7 ± .1 mg/L and 21.1 ± .4 mg/L chloride and sulfate, respectively) (Rockwell _et al_. 1980) with lower concentration Lake Huron waters where NBLH area concentrations of 5.4 mg/L chloride and 15.3-15.5 mg/L sulfate were found in 1980 (Tables 5.3-5.4).

In 1974, Warry (1978a) found North Channel chloride and sulfate concentrations to increase generally from west to east with low levels of 2.7-5.4 mg/L chloride and 8.0-15.1 mg/L sulfate in the WNC, intermediate levels of 4.4-5.5 mg/L chloride and 13.7-15.5 mg/L sulfate in CNC, and higher levels of 4.4-4.8 mg/L chloride and 14.7-15.6 mg/L sulfate in the ENC. In 1980 similar ranges were found in each of these areas (Tables 5.3-5.24).

In 1974, for the central basin of Georgian Bay, Warry (1978b) found S/E chloride and sulfate concentrations of 4.7-4.9 mg/L chloride and 15.2-15.9 mg/L sulfate. In 1980, the S/E chloride ranges were 4.7-5.1 mg/L and sulfate ranged from 14.8 to 15.7 mg/L. In CBGB, chloride and sulfate levels showed no change from 1974 to 1980.

Figure 5.9 shows area sulfate concentrations in S/E and L/H layers. The L/H layer in the North Channel, St. Marys River, and CBGB tended to have higher sulfate concentrations than the S/E layer. This appears to be due to intrusion of water with higher dissolved solids from Lake Huron into the hypolimnion layer in these areas.

A discharge event was observed in the St. Marys River during cruise 4. Elevated levels of chloride (Fig. 5.10) (200% above average), sulfate (about 300% above average), and specific conductance (about 70% above average) were

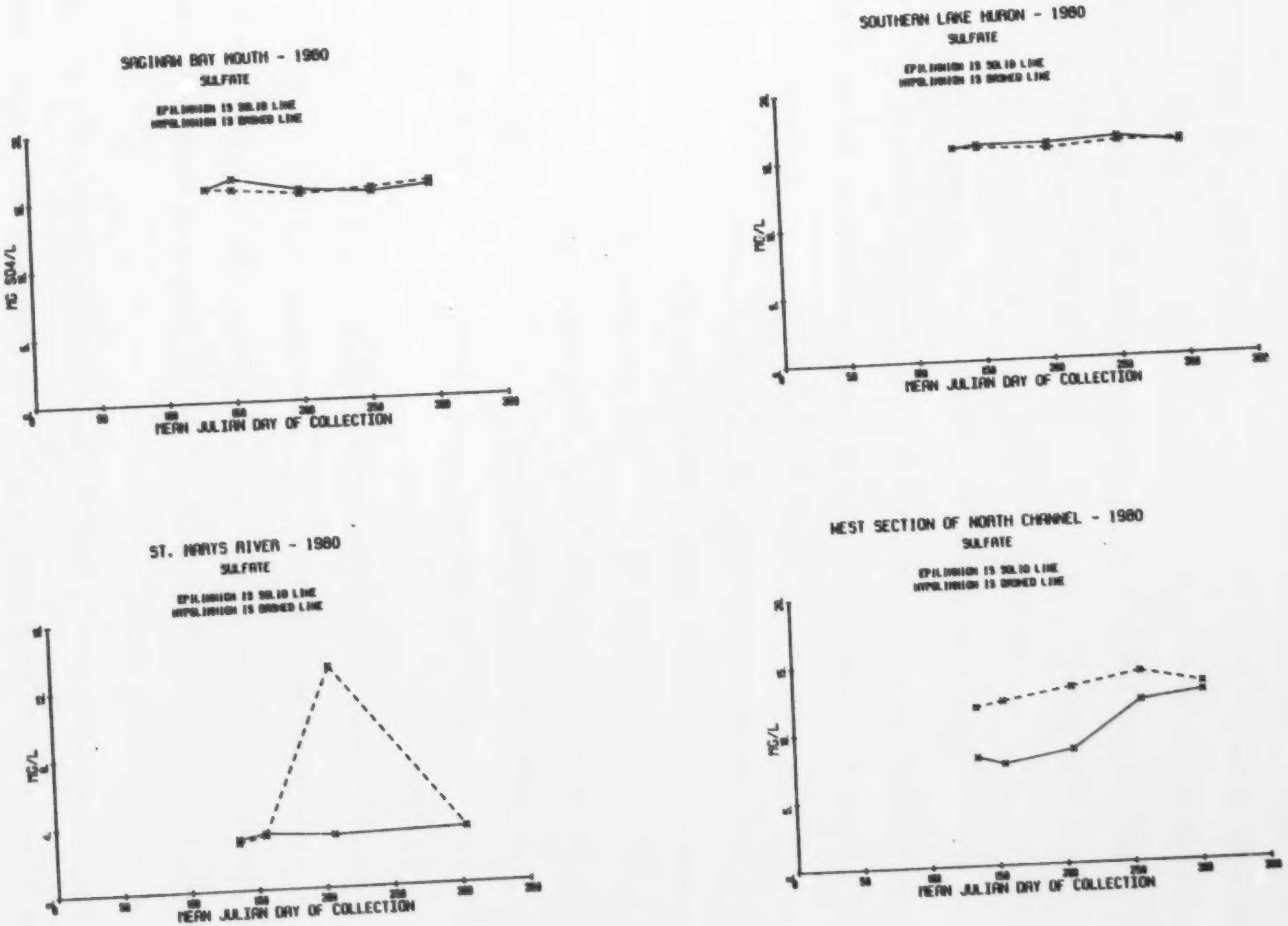


Figure 5.9. Time variation of sulfate during 1980.

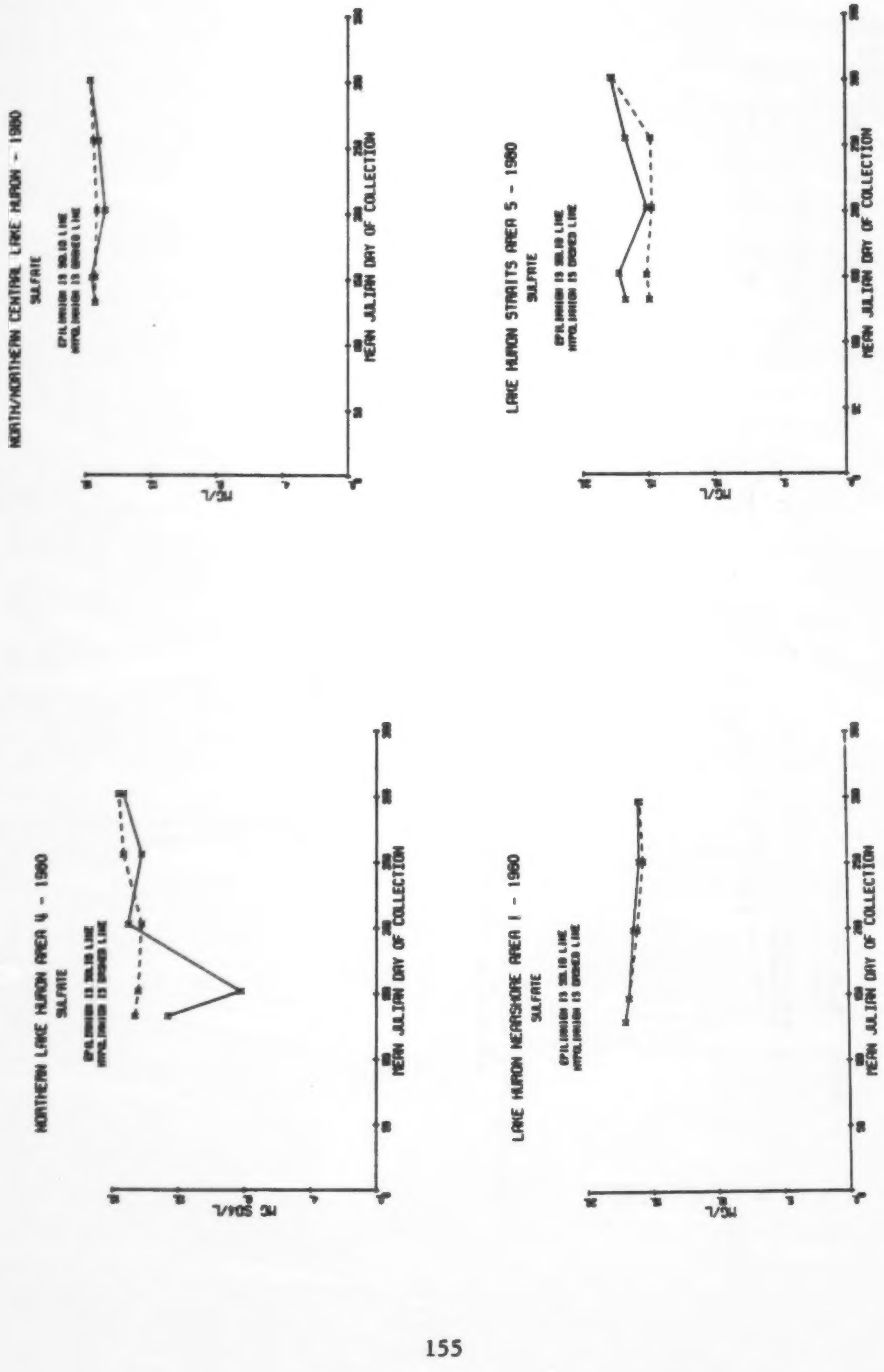


Figure 5.9. (Continued).

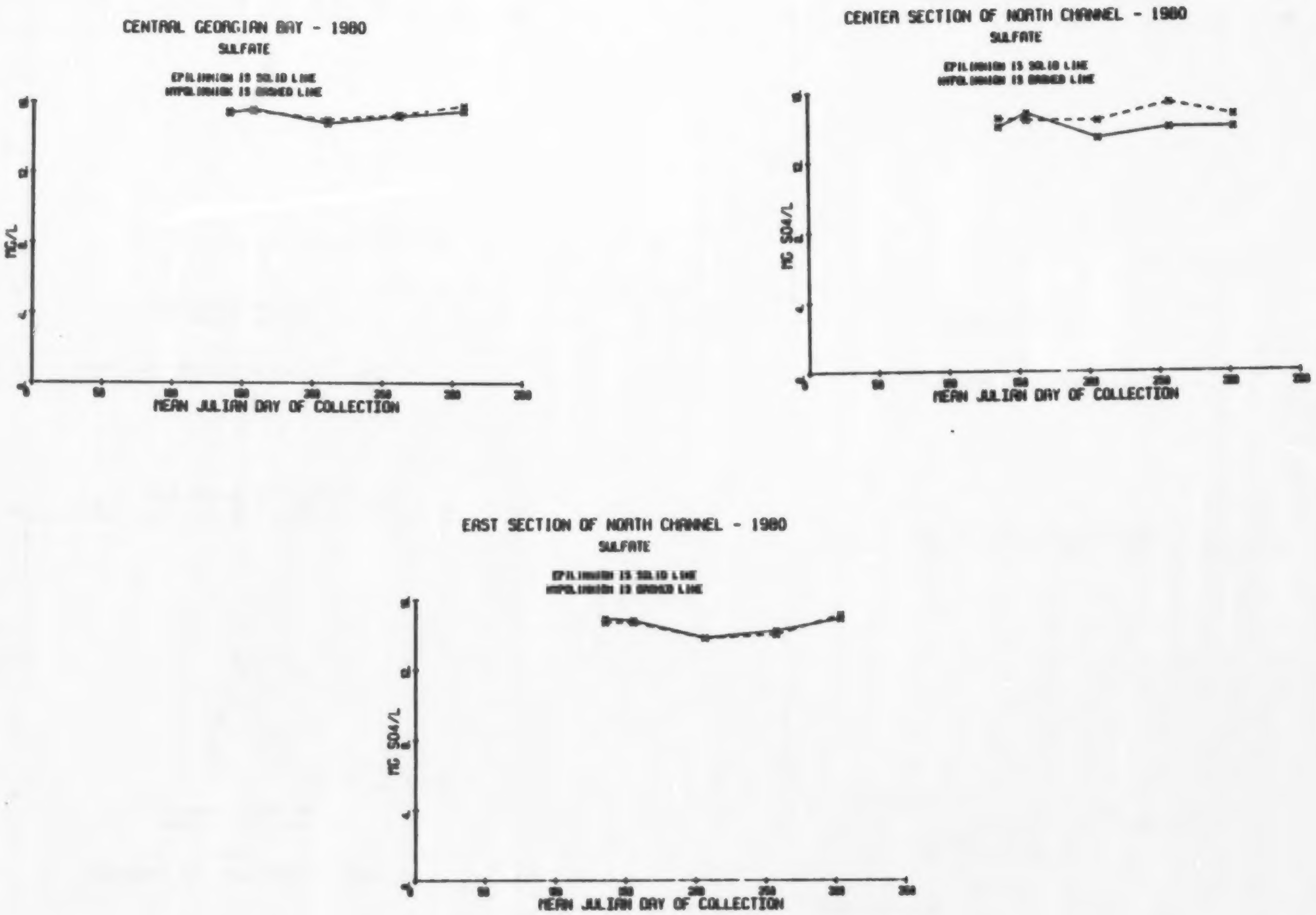


Figure 5.9. (Concluded).

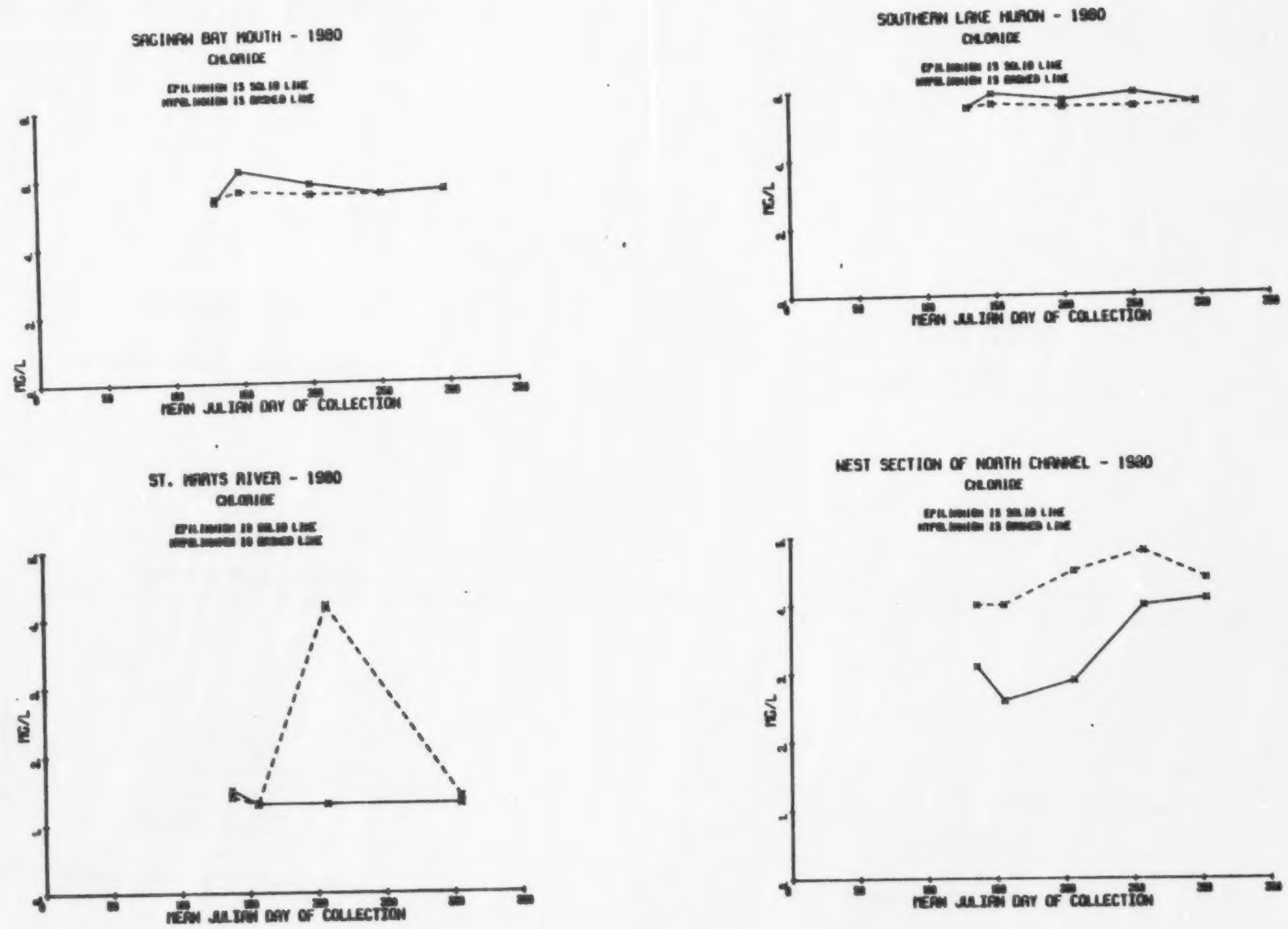


Figure 5.10. Time variation of chloride during 1980.

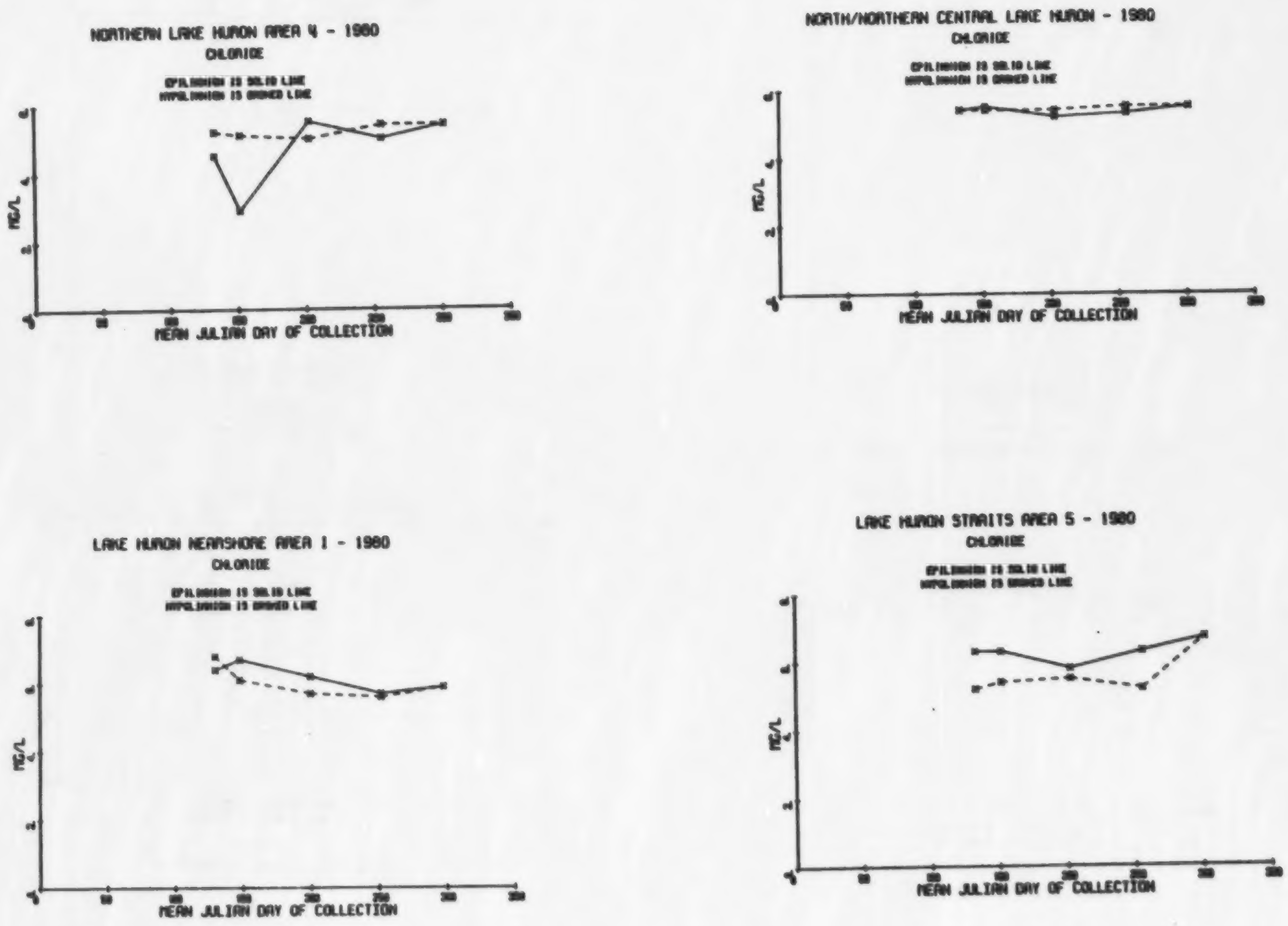


Figure 5.10. (Continued).

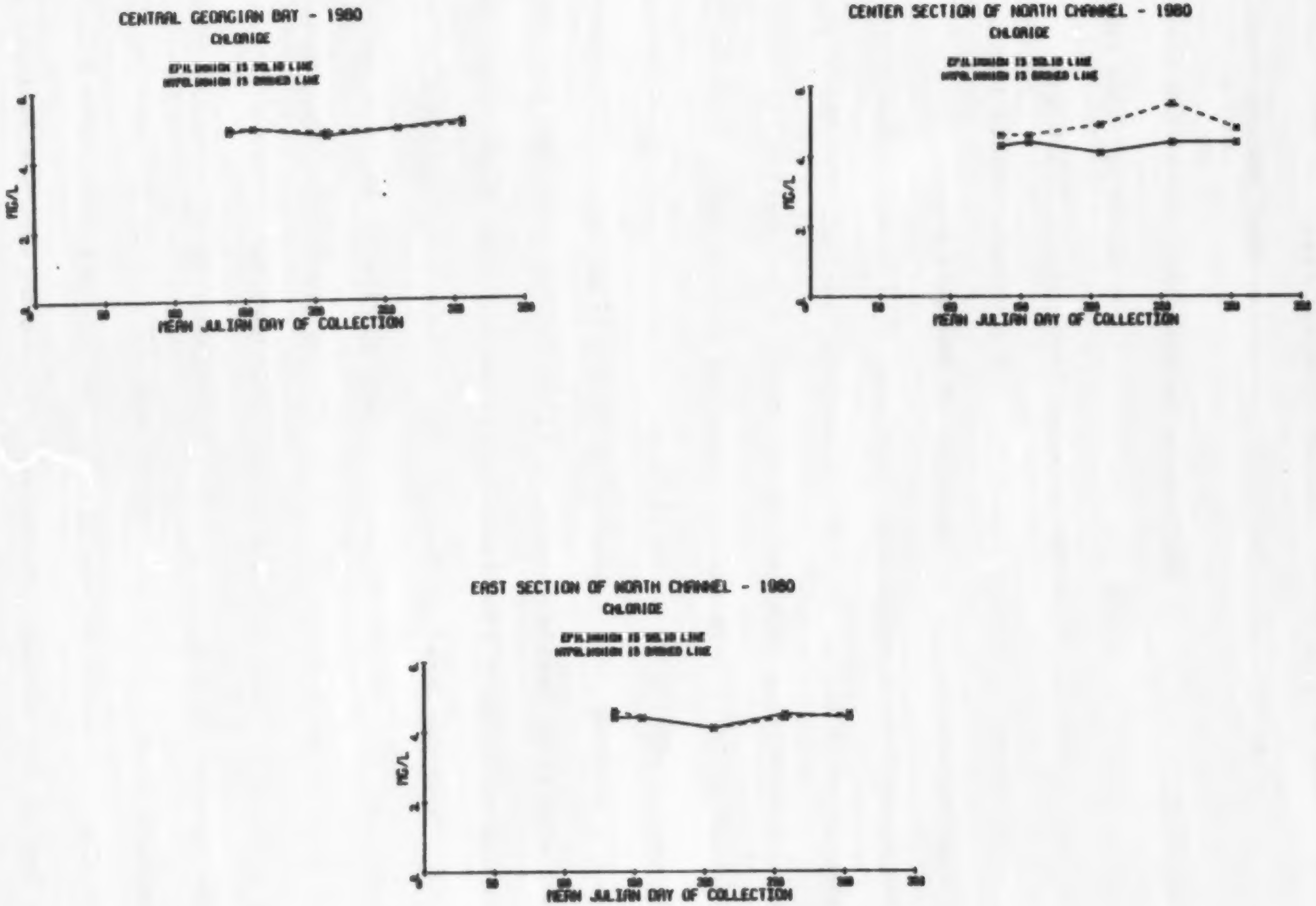


Figure 5.10. (Concluded).

observed. These measurements were associated with the lowest pH measurement of the 1980 season at this site. Similar chemical responses have been observed in areas where pickling liquor is discharged during steel manufacturing.

Alkalinity — Alkalinity differences between the S/E and L/H layers were significantly different at the 95% confidence level at one or more times during the stratified period in 22 of the 27 areas (Appendix A, Table A-8). This occurred most frequently during cruise 4. The increased levels in the hypolimnion are associated with the accumulation of CO_2 (Hutchinson 1957).

Large variations in areal alkalinity concentrations are due to the different sources of water rather than due to seasonal variations. The lowest alkalinity measurements were found at the St. Marys River station with annual mean levels of 43.2 mg $CaCO_3$/L in the S/E layer and 47.7 mg $CaCO_3$/L in the L/H layer. The hypolimnetic alkalinity value of 71 mg $CaCO_3$/L was associated with unusually high sulfate, chloride, and conductivity values (Fig. 5.11). Lake Superior waters had alkalinity levels between 42-45 mg $CaCO_3$/L (Schelske and Roth 1973). The North Channel's lower alkalinity values reflect Lake Superior source waters and drainage from the Canadian Shield. The highest alkalinity values were found in the open lake area (A5LH) with values ranging from 85 to 92 mg $CaCO_3$/L with an annual mean cruise average of 88.3 mg (Tables 5.3-5.24). A5LH is most directly affected by Lake Michigan water. Northern basin Lake Michigan alkalinity was reported around 110 mg $CaCO_3$/L (Rockwell et al. 1980).

Nearshore areas G and I had similar high alkalinity levels. Nearshore area G is also influenced by Lake Michigan water. Nearshore area I is influenced by Saginaw Bay outputs. Nearshore area G mean annual alkalinity concentrations were 80.5 mg $CaCO_3$/L in the S/E layer and 79.7 mg $CaCO_3$/L in the L/H

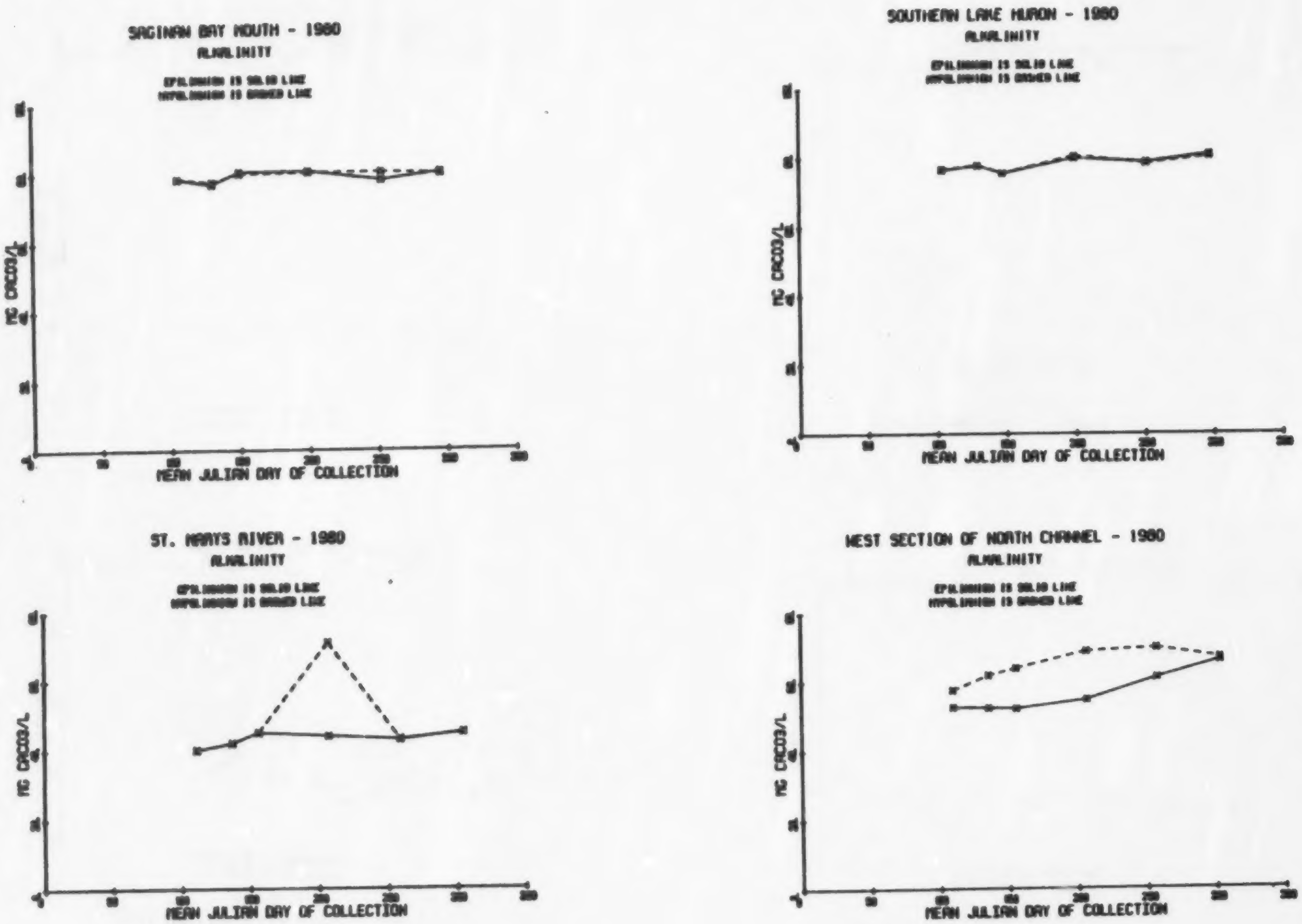


Figure 5.11. Time variation of alkalinity during 1980.

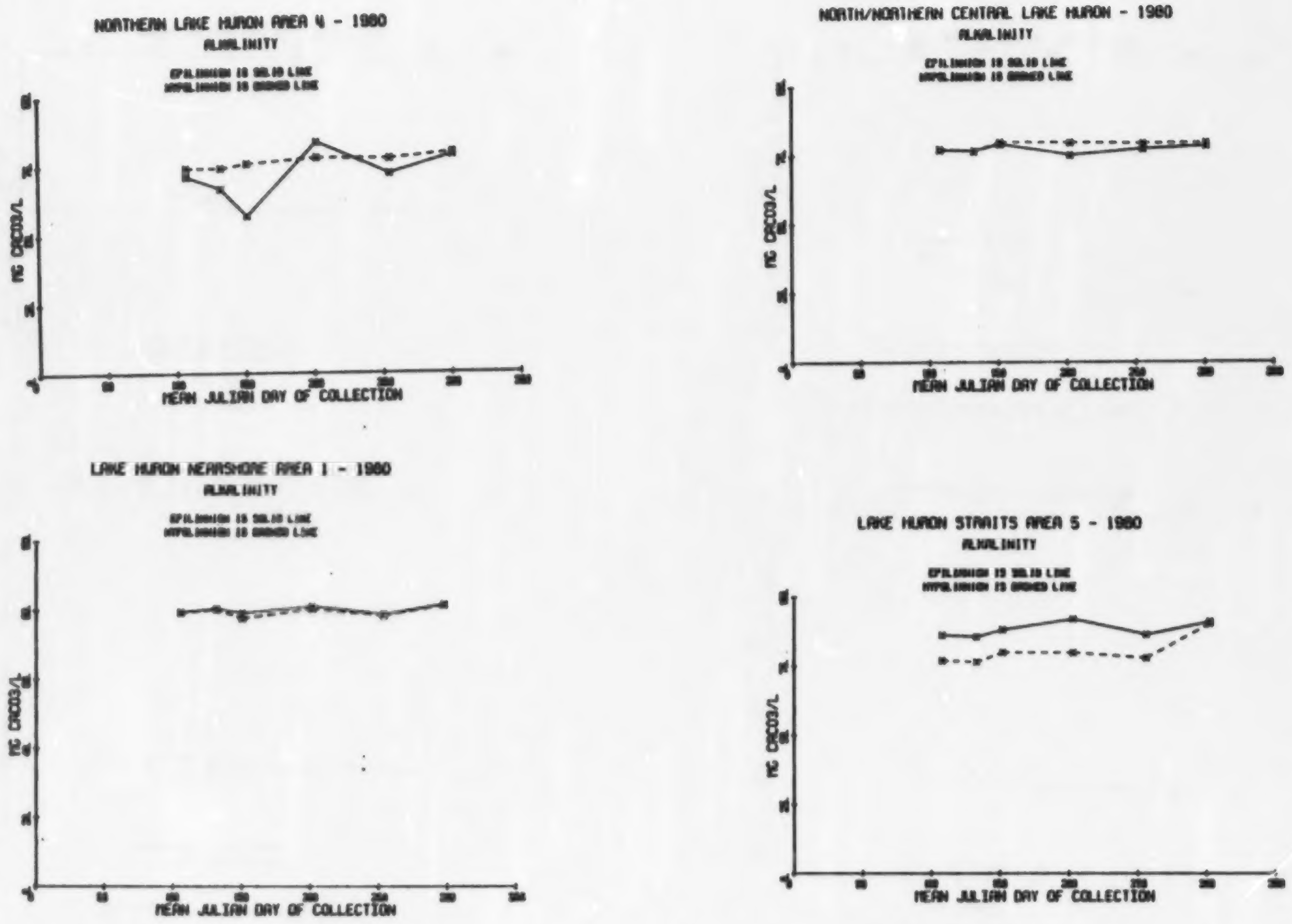
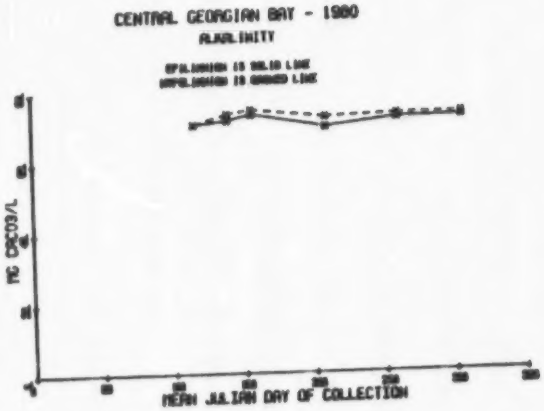
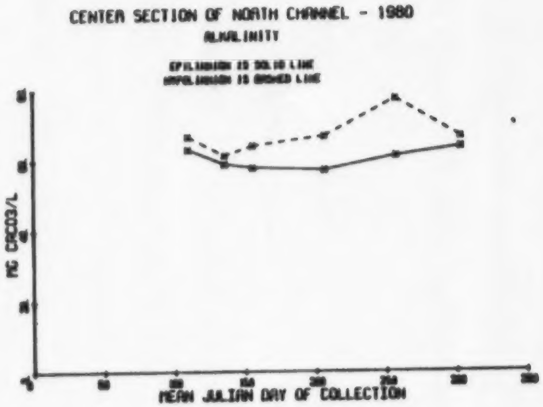


Figure 5.11. (Continued).





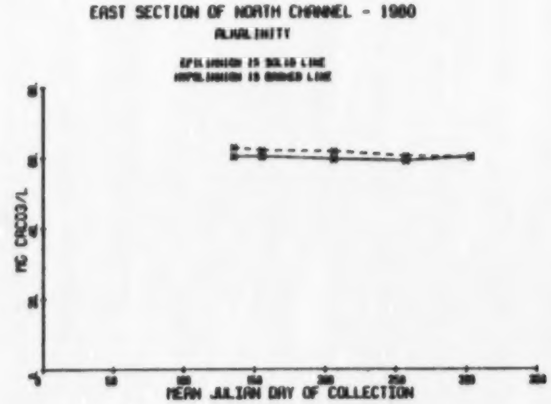
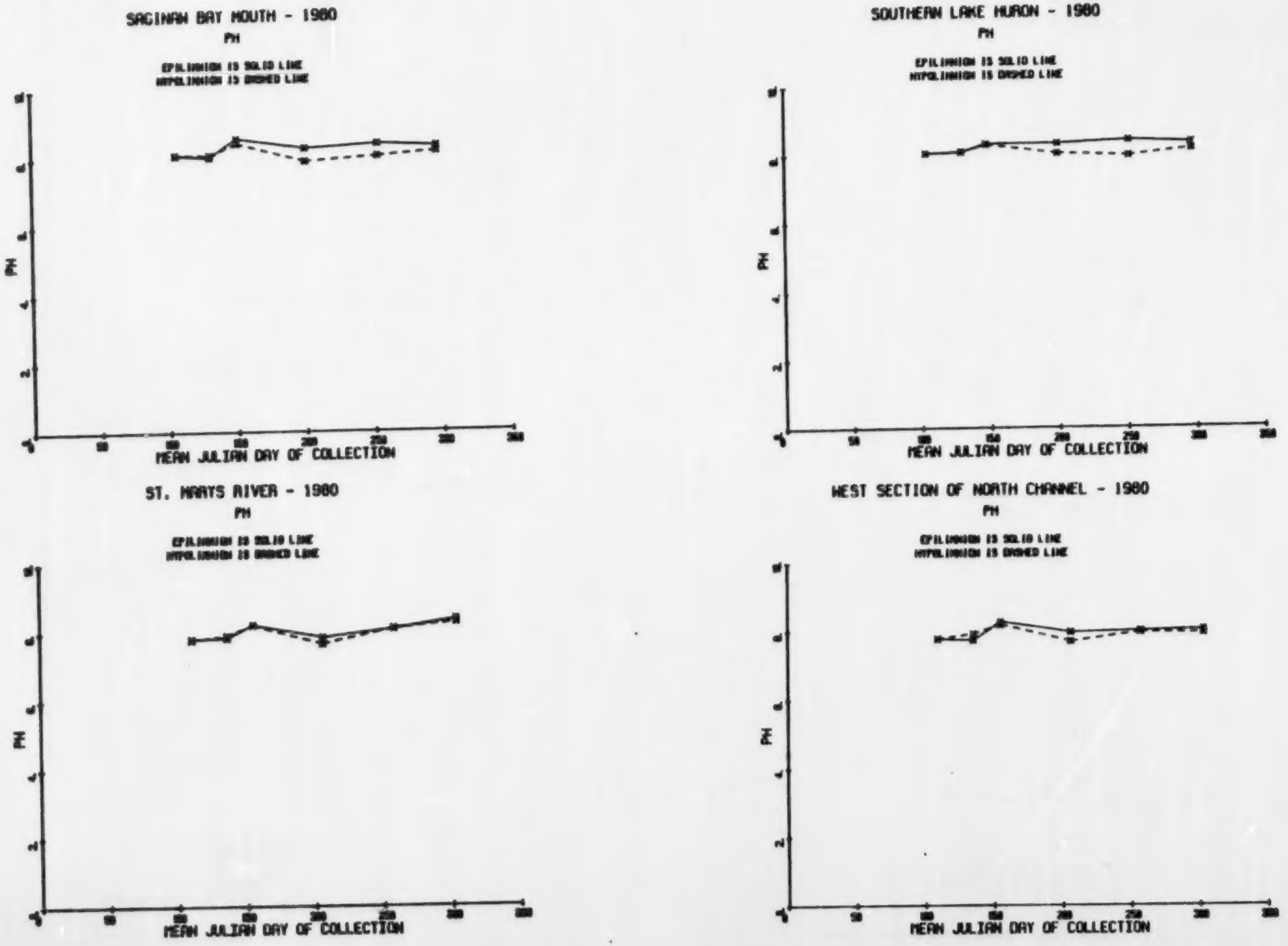


Figure 5.11. (Concluded).

layer. Nearshore area I mean annual alkalinity concentrations were 80.3 mg $CaCO_3$/L in the S/E layer and 79.8 mg $CaCO_3$/L in the L/H layer (Tables 5.3-5.24). The open lake (NBLH, SBM, and SBLH) mean cruise alkalinity concentrations in the S/E and L/H layers ranged between 74 and 81 mg $CaCO_3$/L with SBM values slightly higher (Fig. 5.3, Tables 5.3-5.24).

Central basin Georgian Bay (CBGB) mean cruise alkalinity concentrations ranged between 69 and 75 mg $CaCO_3$/L in the S/E and L/H layers (Fig. 5.3, Tables 5.3-5.24). L/H alkalinity values tended to be higher in the deep water areas and the North Channel. In areas influenced by high alkalinity source waters (A5LH, NS-I, SBM), the reverse was generally true (Fig. 5.3). Warry (1978b) reported alkalinity between 51.5 and 73.8 mg $CaCO_3$/L (WNC), between 57.9-75.7 mg $CaCO_3$/L (CNC), and between 60.4-64.8 mg $CaCO_3$/L (ENC). Warry (1978a) reported alkalinity between 68.2-72.6 in the epilimnion of CBGB. These levels were similar to those found in 1980.

pH — The pH values were statistically different between the S/E and L/H layers during several cruises in 1980 (Fig. 5.12). Cruise 4 accounted for the majority of these occurrences (Appendix A, Table A-9). The pH values were usually above 7.8 for cruise means in the S/E and L/H layers in all areas. Slightly lower S/E pH values were observed in WNC during cruises 1 and 2. This may reflect acid spring runoff from the Canadian Shield. The pH values in the L/H layer tended to be more acidic (lower pH values) in some areas (Fig. 5.4). This pattern was observed in Lake Michigan (Rockwell et al. 1980) and is probably due to higher CO_2 concentrations in the colder L/H layer (Hutchinson 1957).


SAGINAW BAY MOUTH - 1980

SOUTHERN LAKE HURON - 1980

ST. MARYS RIVER - 1980

WEST SECTION OF NORTH CHANNEL - 1980

Figure 5.12. Time variation of pH during 1980.

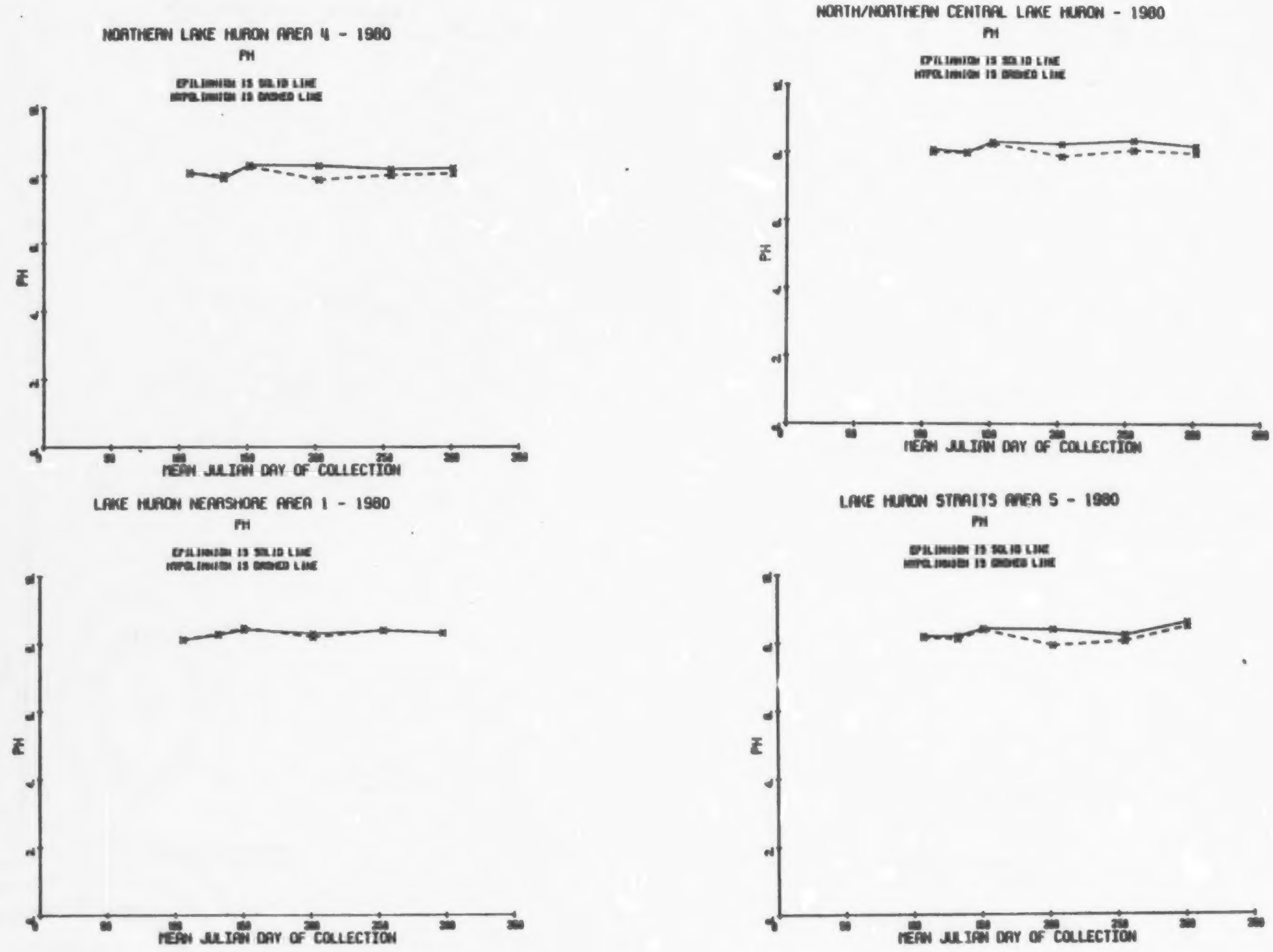
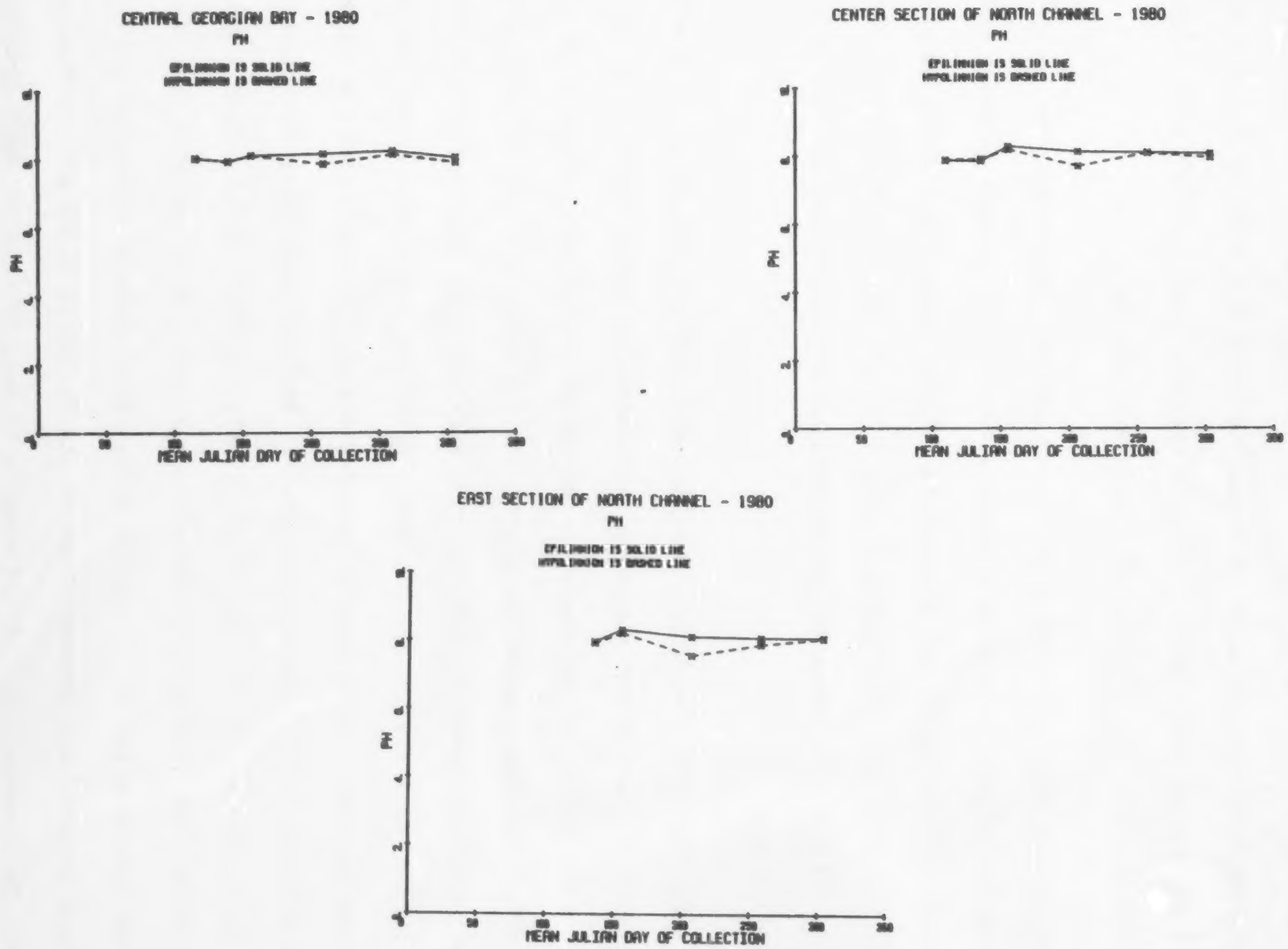


Figure 5.12. (Continued).


CENTRAL GEORGIAN BAY - 1980

CENTER SECTION OF NORTH CHANNEL - 1980

EAST SECTION OF NORTH CHANNEL - 1980

Figure 5.12. (Concluded).

In 1974, Warry (1978a) reported mean pH values between 7.8 and 8.2 with a maximum of 8.4 and a minimum of 7.6 in the North Channel. In CBGB, Warry (1978b) reported mean pH to range between 8.0 and 8.2 with a high of 8.6. Areal pH extreme values reported in 1980 were slightly lower in CBGB with a hypolimnion low of 7.85, but overall, pH levels were similar.

Dissolved Oxygen -- Dissolved oxygen (DO) was seldom depleted in 1980, and the overall average percentage saturation was 99% or greater on every cruise for all areas of Lake Huron and Georgian Bay (Table 5.28). The lowest observed DO saturation (70%) occurred during cruise 2 at Lake Huron station 27 in the bottom sample. Figure 5.13 shows DO concentrations in the S/E and L/H layers in ten selected areas.

Major Metals -- The alkali metals, potassium and sodium, and the alkaline earth metals, calcium and magnesium, were measured during cruise 1 in all areas except part of CNC and ENC where ice prevented operations. Table 5.29 contains the surface and lower layer concentrations for these metals. Concentrations of these metals are lower in Lake Superior water than in Lake Huron (Schelske and Roth 1973). As a result, the St. Marys River had the lowest concentration of these parameters. The average concentrations of all samples at the St. Marys River station were .70 mg/L potassium, 1.5 mg/L sodium, 2.8 mg/L magnesium, and 13.4 mg/L calcium. Weiler and Chawla (1969) reported Lake Superior calcium concentration at 13.2 mg/L and Schelske and Roth (1973) reported Lake Superior calcium concentration at 14.5 ± 1.5 mg/L. North Channel areas had metal concentrations intermediate between those of the St. Marys River and those of Lake Huron. The average value of all samples in area CNC was .93 mg/L potassium, 3.0 mg/L sodium, 22.6 mg/L calcium, and 6.0 mg/L magnesium. In most areas,

Table 5.28. Dissolved oxygen concentrations in Lake Huron.

Zone	Average D.O. 95% confidence Interval (in zone)		Range of % Saturation (in zone)	Average D.O. % for Cruise Entire Lake All Samples	Range of % Saturation Entire Basin
Cruise 1					
	Ave	Range	Range		
CBGB	14.2	14.1-14.4	102-106	GB 104	95-109
SBLH	14.4	14.2-14.7	97-108	LH 103	79-113
NBLH	13.6	13.2-14.1	82-104		
Cruise 2					
CBGB	13.5	13.3-13.7	98-105	GB 104	98-112
SBLH	14.0	13.8-14.2	102-110	LH 105	70-118
NBLH	13.6	13.0-14.1	70-116		
Cruise 3					
CBGB	13.2	13.1-13.5	103-111	GB 106	100-115
SBLH	13.7	13.6-13.8	104-111	LH 106	98-116
NBLH	13.7	13.6-13.7	102-108		
Cruise 4					
CBGB	12.2	11.8-12.5	89-107	GB 100	86-115
SBLH	11.7	11.0-12.4	85-100	LH 103	85-121
NBLH	12.5	12.3-12.7	93-102		
Cruise 5					
CBGB	11.3	11.0-11.6	85-119	GB 100	85-122
SBLH	10.9	10.4-11.3	79-133	LH 102	79-133
NBLH	11.9	11.7-12.2	88-121		
Cruise 6					
CBGB	11.8	11.7-12.0	95-107	GB 100	85-115
SBLH	11.0	10.9-11.1	89-105	LH 99	89-111
NBLH	12.0	11.9-12.2	90-111		

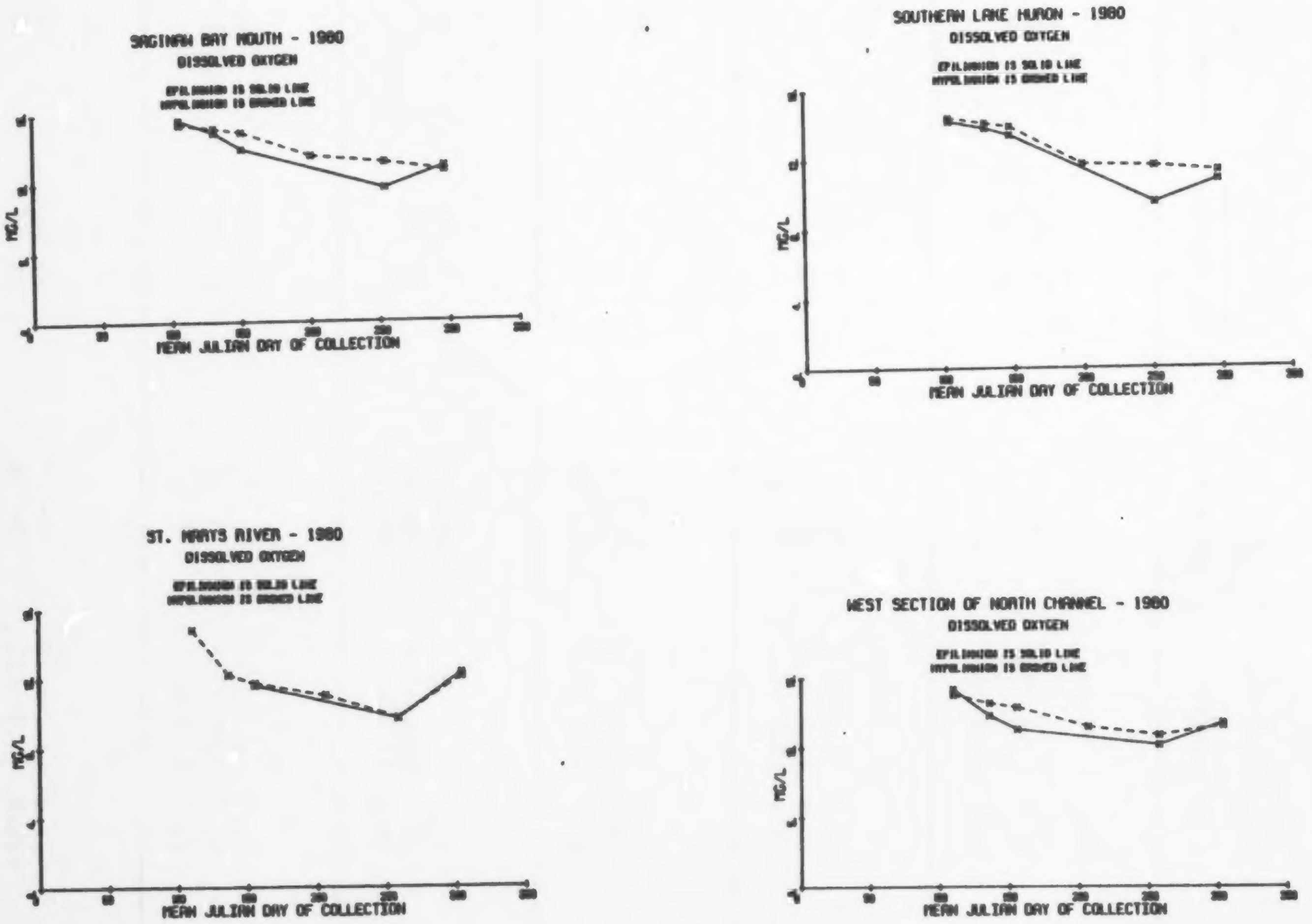


Figure 5.13. Time variation of dissolved oxygen during 1980.

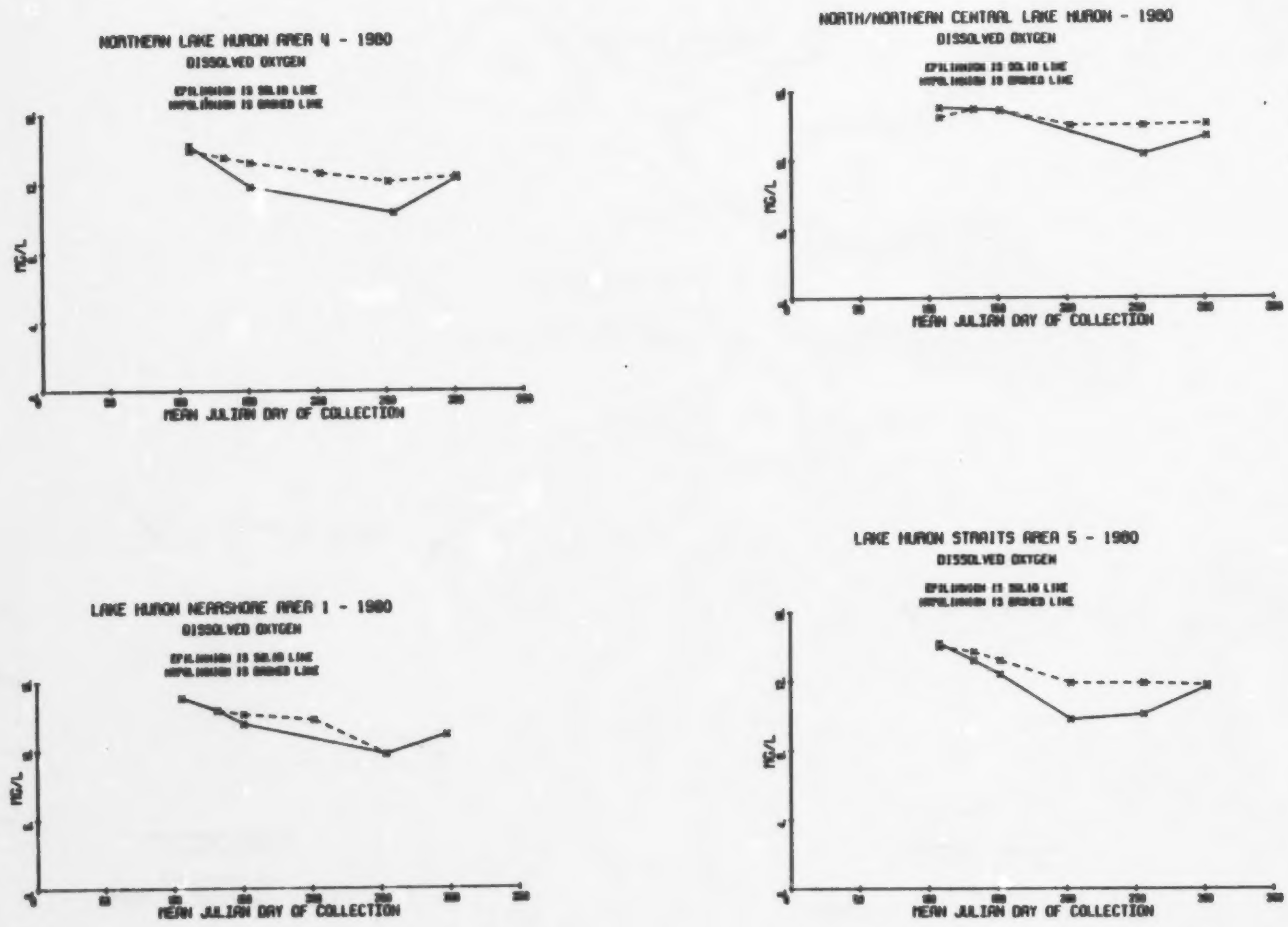


Figure 5.13. (Continued).

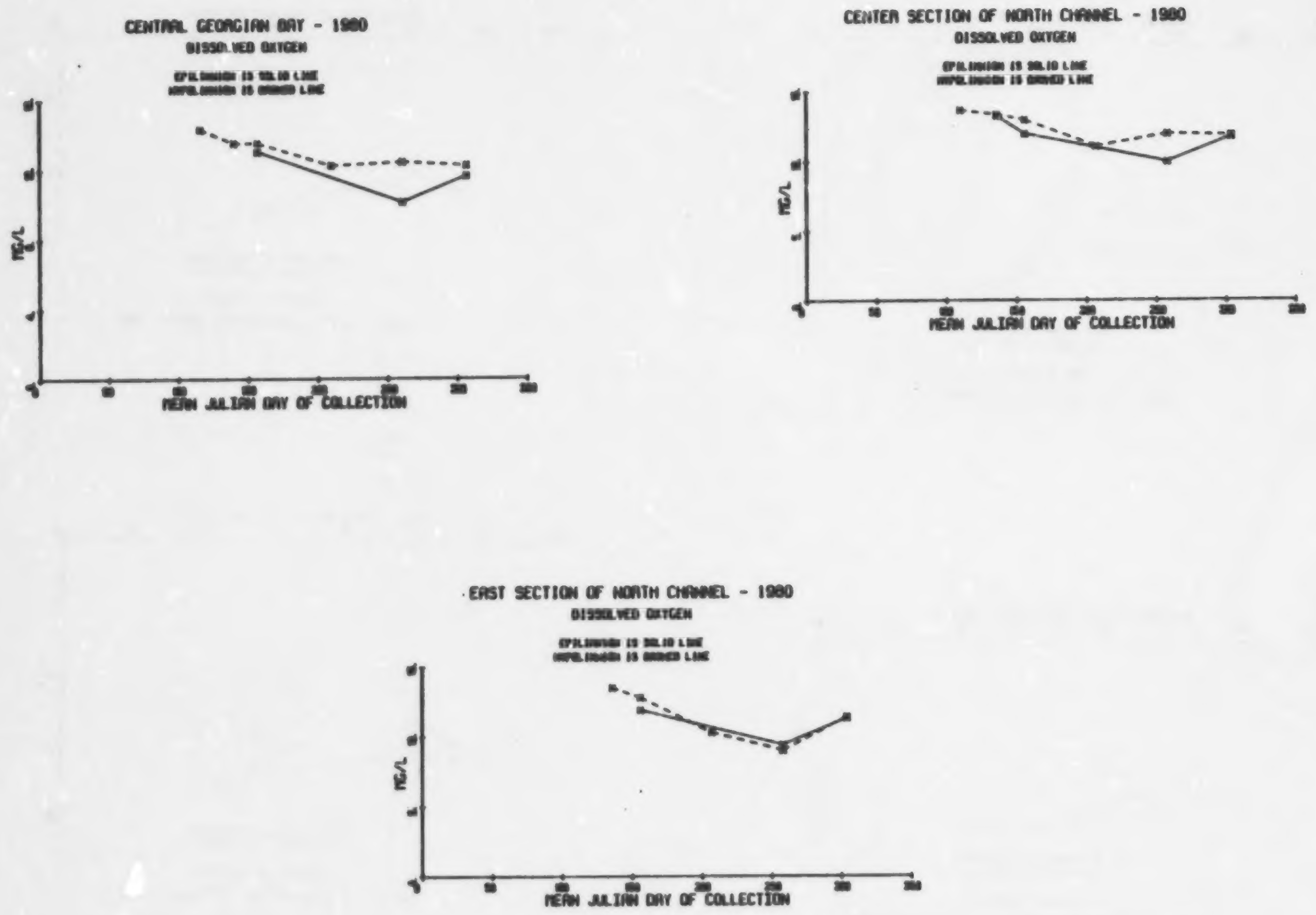


Figure 5.13. (Concluded).

Table 5.29. Major ion concentrations in Lake Huron during April 1980 (cruise 1). Unstratified thermal conditions were present at all stations. The three values represent the arithmetic mean, the 95% confidence interval in brackets, and the number of samples in parentheses.

		Surface Samples				Near-bottom Samples			
Acronym	Stations	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
					LAKE HURON				
A4LH	60,65,66,67	24.2 [21.4-27.1] (4)	6.4 [5.4-7.4] (4)	3.3 [2.8-3.7] (4)	0.84 [0.69-0.99] (4)	24.2 [21.8-26.6] (5)	6.6 [6.0-7.1] (5)	3.2 [2.3-4.1] (5)	0.95 [0.84-1.10] (4)
A5LH	56,62,63,64	27.6 [24.0-31.2] (4)	8.0 [6.3-9.7] (4)	3.6 [2.8-4.3] (4)	1.0 [0.86-1.20] (4)	24.8 [7.7-42.0] (2)	6.9 [0.78-13.0] (2)	3.1 [0.79-6.1] (2)	0.97 [0.97-0.97] (2)
NBLH	27,29,31-33, 37-38,43-45, 48,51-54,57,61	26.4 [25.8-26.8] (14)	7.1 [7.0-7.2] (14)	3.3 [3.1-3.6] (14)	1.00 [0.95-1.06] (14)	25.9 [25.3-26.4] (10)	6.9 [6.8-7.0] (10)	3.4 [3.0-3.8] (10)	1.06 [0.99-1.12] (10)
SBLH	6,9,12,15, 90-93	27.0 [26.5-27.5] (8)	7.4 [7.2-7.6] (8)	3.5 [3.2-3.7] (8)	0.94 [0.87-1.00] (8)	26.4 [25.8-27.1] (13)	7.2 [7.0-7.3] (13)	3.4 [3.1-3.6] (13)	0.92 [0.86-0.99] (13)
SBM	16,18-21, 24,26	26.5 [25.7-27.4] (7)	7.1 [6.8-7.3] (7)	3.5 [3.2-3.8] (7)	0.96 [0.92-0.99] (7)	26.9 [26.4-27.4] (10)	7.2 [7.1-7.4] (10)	3.6 [3.3-3.8] (10)	1.05 [1.01-1.10] (10)
WNC	68,70-72, 75-76	16.1 [11.2-21.3] (6)	3.9 [2.5-5.6] (6)	2.0 [1.4-2.7] (6)	0.80 [0.57-0.95] (6)	19.2 [16.2-22.1] (7)	4.9 [4.0-5.9] (7)	2.5 [2.0-3.0] (7)	0.85 [0.78-0.92] (7)
CNC	73-74, 77-86	22.7 [20.9-23.4] (3)	6.0 [5.5-6.2] (3)	3.1 [2.4-3.6] (3)	0.93 [0.89-0.93] (3)	22.5 [20.9-24.3] (6)	6.0 [5.5-6.5] (6)	3.0 [2.7-3.3] (6)	0.94 [0.88-1.00] (6)
ENC	87-89	ICE COVERED — NO SAMPLES							
NS-I	7,13-14,17, 23,25,94	27.3 [27.0-22.6] (21)	7.3 [7.2-7.4] (21)	3.6 [3.6-3.7] (21)	1.02 [0.95-1.10] (18)	27.4 [26.7-28.0] (7)	7.3 [7.2-7.5] (7)	3.6 [3.5-3.6] (7)	0.98 [0.88-1.10] (6)
RIVER	69	13.4 [13.4-13.4] (1)	29.0 [29.0-29.0] (1)	1.4 [1.4-1.4] (1)	0.70 [0.70-0.70] (1)	13.3 [13.3-13.3] (1)	28.0 [28.0-28.0] (1)	1.6 [1.6-1.6] (1)	0.70 [0.70-0.70] (1)
					GEORGIAN BAY				
CBGB	111,113-114,117-118,121-122, 124,128-130,137	25.4 [24.2-26.7] (12)	6.8 [6.5-7.1] (12)	3.0 [2.8-3.2] (12)	0.88 [0.82-0.94] (12)	25.2 [23.8-26.6] (11)	6.8 [6.4-7.2] (11)	2.8 [2.7-3.0] (11)	0.93 [0.66-1.20] (11)

Georgian Bay metal concentration levels were 1 to 2 mg/L lower for sodium, magnesium, and calcium than for the rest of Lake Huron. CBGB metal levels were .91 mg/L potassium, 2.9 mg/L sodium, 6.8 mg/L magnesium, and 25.5 mg/L calcium. In Lake Huron, the highest metal levels were in areas influenced by Lake Michigan (A5LH) and Saginaw Bay (SBM, NS-I) waters. Lake Michigan waters contain 1.1 mg/L potassium, 4.8 mg/L sodium, 10.8 mg/L magnesium, and 34.9 mg/L calcium (Rockwell et al. 1980). NBLH is representative of open lake metal concentrations. For all NBLH samples the concentrations were 1.0 mg/L potassium, 3.3 mg/L sodium, 7.0 mg/L magnesium, and 26.1 mg/L calcium.

Comparison of 1980 to 1974 Segmentation Results -- Comparison of nearshore areas A, B, C, D, E, F, G, and I results from 1980 with those of 1974 shows chemical changes suggestive of improved water quality (Table 5.30) between these 2 years. Secchi disk measurements in 1980 were greater in six of eight areas. Total phosphorus concentrations were lower in 1980 in seven areas. Total nitrogen levels were higher in five areas, with one area showing no change. Dissolved reactive silica concentrations were higher in six areas, with one area showing no change. Only two areas had decreased chlorophyll a measurements. Dissolved substances changes were mixed, with conductivity and sulfate showing increased concentration levels in a majority of the areas and chloride showing a decrease in a majority of the areas. (Data tables are found in Appendix B.)

These observations should be used with caution because they are based on an annual comparison. The results can be biased between the years due to different cruise frequencies and areal station patterns, especially in the nearshore areas. There appears to be a general reduction in nearshore phosphorus levels, with some Canadian areas having large TP reductions between 1974 and 1980.

Table 5.30. Comparison of 1974 and 1980 epilimnetic/surface waters (1-10 m) in nearshore areas for selected parameters.

Nearshore Areas	A	B	C	D	E	F	G	I	Summary +	 -	 0
Secchi Disk	+	+	+	+	+	+	-	-	6	2	0
TP	-	-	-	-	-	-	0	-	0	7	1
TN	+	-	0	+	-	+	+	+	5	2	1
DRS	+	+	0	+	+	-	+	+	6	1	1
Chlorophyll a	+	-	+	+	+	+	+	-	6	2	0
Conductivity	+	-	+	0	+	-	+	+	5	2	1
Cl^-	+	-	-	-	-	-	+	+	3	5	0
SO_r	+	-	+	-	+	+	+	+	6	2	0

1980 value - 1974 value > 0 is +
1980 value - 1974 value < 0 is -
1980 value - 1974 value = 0 is 0

In 1974, one season was omitted in areas A, B, C, D, G, and I. For some of these areas, decreases in total phosphorus are quite large: areas A (approx. 21.5 ppb), B (approx. 15.5 ppb), C (approx. 5 ppb), and F (approx. 7.5 ppb). There appears to be a general reduction in nearshore phosphorus levels, with some Canadian areas having large TP reductions between 1974 and 1980.

Comparison of 1980 open lake segments with the 1974 areas for five parameters (Table 5.31) also shows a decrease in total phosphorus concentrations. The 1980 results suggested that total phosphorus levels decreased in 18 of the 19 areas, and dissolved nitrate + nitrite increased in 14 of the 19 areas. These changes were consistent with improved trophic status. The dissolved reactive silica (DRS) levels were lower in 13 of the 19 areas. The conservative ions were evenly split between increased levels, no change, and decreased levels.

Comparison of areas A4LH, A5LH, NBLH, SBM, SBLH, and CBGB for nutrient depletion in 1980 with that found in 1974 showed about 50% less depletion in 1980 for DRS and DNN. This is both statistically and environmentally significant. In these areas, DRS depletion in 1980 was 41±2% while in 1974 these areas had an average depletion of 65±4% (IJC 1976). DNN depletion in 1980 was 22±2%, while in 1974 the areas reported had an average depletion of 43±4% (IJC 1976). Depletion of silica and nitrate in the epilimnion increases with increasing degrees of eutrophication (Schelske 1975). Between 1974 and 1980, the opposite effect occurred, suggesting improved trophic conditions.

Comparison of the epilimnion 1974 to 1980 areal analysis results with the 1968 to 1980 year time series analysis (Chapter 8 - Table 8.7) provides some useful inferences. For the areal results (Table 5.31), chloride and conductivity were about evenly split between increases and decreases. The long-term

Table 5.31. Comparison of 1974 and 1980 epilimnetic/surface (1-10 m) in open lake areas for selected parameters.

Open Lake Areas						
1974 Acronym	1980 Acronym	TP	DRS	DNN	Cl	Cond
			North Channel			
1	WNC	-	-	+	+	+
2	CNC	-	-	+	0	-
3a	ENC	-	-	-	-	-
			Lake Huron			
4	A4LH	-	-	-*	-	-
5	A5LH	0	-	+*	-	-
6	NBLH	-	-	+*	0	0
7	SBM	-	-	-*	-	-
8	SBLH	-	+	-*	-	-
9		+	-	-*	+	-
			Georgian Bay			
10		-	+	+	+	+
11		-	+	+	+	+
12		-	-	+	0	-
13		-	-	+	+	+
14		-	-	+	0	+
15		-	+	+	+	-
16		-	-	+	0	+
17	CBGB	-	-	+	+	+
18		+	+	0	-	-
3		-	-	+	+	+

1980-1974 value > 0 is +
1980-1974 value = 0 is 0
1980-1974 value < 0 is -
*Comparison was made between total nitrogen for 1974 and nitrate plus nitrite for 1980. Decreases are probably not real.

trend analysis showed increasing and decreasing trends within the homogeneous water mass, depending on the season. The areal results taken together suggested decreasing total phosphorus and dissolved reactive silica trends and increasing nitrate-nitrogen trends. Except for total phosphorus, these results are supported by the long-term trend analysis.

This suggests that an individual area result may be indicative of long-term changes. Further, if an individual area result is supported by a majority of areas, then more sophisticated statistical analysis (see Chapter 8) must confirm the direction of change.

Total Phosphorus-Ice Cover Relationship -- What may be the cause (or causes) of these changes? Because the collection of changes suggests improvements in water quality, the apparent improvements in water quality may not be just normal environmental variation in an oligotrophic system. Lower total phosphorus levels have also been observed in Lakes Michigan (Bowden _et al_. 1981) and Ontario (Kwiatkowski 1982) during this time period. The phosphorus decreases in these lakes, as well as in Lake Huron, cannot be explained solely by cultural controls on phosphorus loadings. Thus, an additional mechanism which can influence the entire Great Lakes basin is suggested.

The reduced total phosphorus levels found during 1980 follow a series of colder winters. Figure 5.14 shows several measures of the extent of the cold winters in the late 1970s and the spring cruise total phosphorus concentrations. Cumulative days of percent ice cover in the winters of 1976-77 through 1978-79 were more than twice that which occurred in five of the six winters during 1971-76. Maximum areal ice covers occurred in the winters of 1976-77 and 1978-79. A more complete settling of particulate matter occurred in the winters

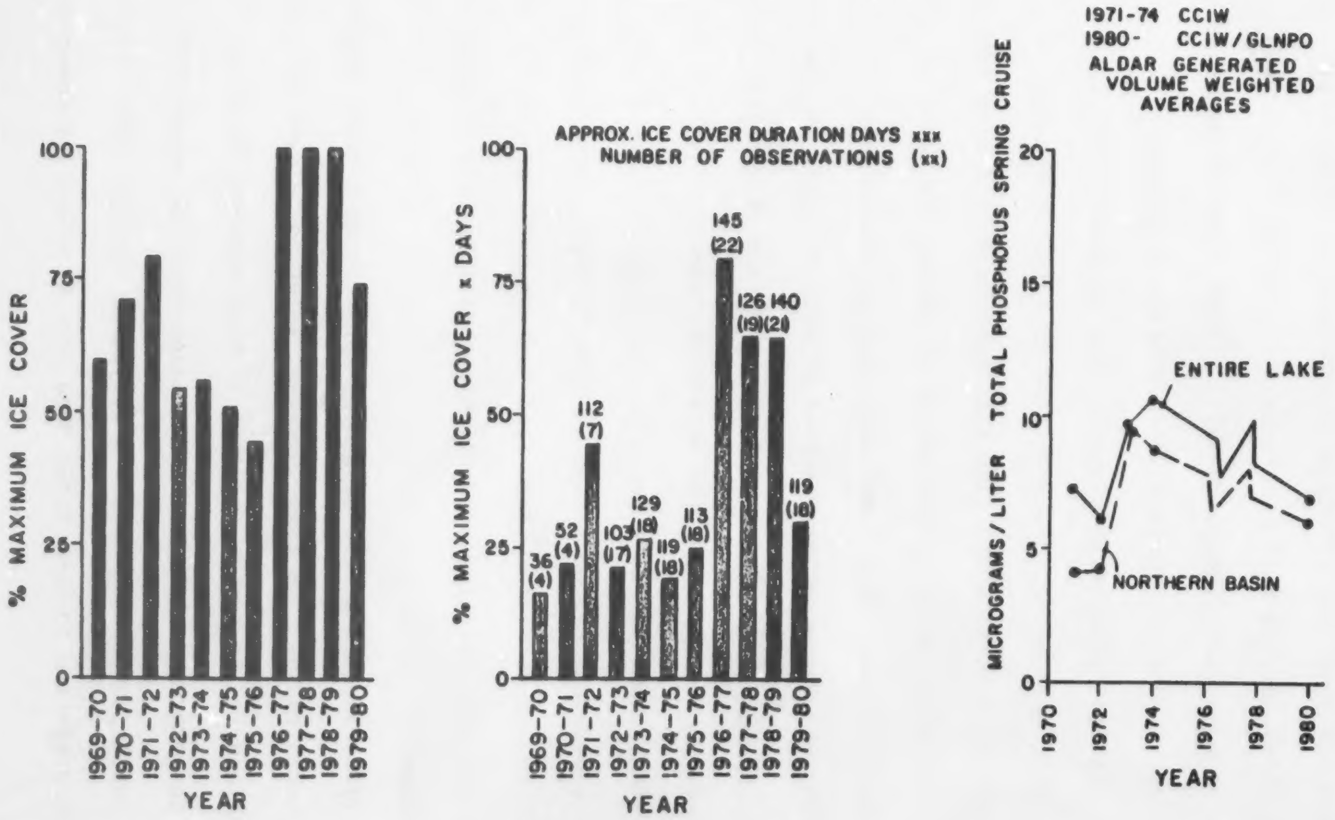


Figure 5.14. Ice cover, ice duration, and spring total phosphorus for Lake Huron.

of 1977-79 than otherwise would have occurred. Wind stress effects would have been reduced by the more extensive ice covers. A statistical relationship between maximum ice cover and spring total phosphorus concentration levels has been shown to exist in Lake Michigan, Lake Ontario, central and eastern Lake Erie, as well as Lake Huron (Rockwell 1981). This study showed that ambient phosphorus levels tended to decrease after winters with extensive ice covers and tended to increase after mild winters. The decreases were larger than the increases with a resulting net reduction in total phosphorus.

Rodgers and Salisbury (1981) used the hypothesis of a time variable setting velocity in their model study of the effect of winter ice cover on the water quality in Lake Michigan. They found that they could simulate the reduction in total phosphorus concentration observed in Lake Michigan between 1976 and 1977 (Rockwell _et al_. 1980) by assuming that the rate of particle removal from the water column was dependent on the extent of lake ice cover.

Lesht (1984a) examined the effects of this assumption on a long-term simulation of phosphorus concentration in Lake Michigan using a simple mass balance model, forced with historical load estimates (Chapra 1977), and found that the time variable settling velocity hypothesis is consistent with observed phosphorus concentrations.

Lesht (1984b) applied a time-dependent solution to a multi-segment model of the Great Lakes basin. The time-dependent solution is used to evaluate year-to-year variations in the system response to time-variable forcing. The average annual total phosphorus in Lake Huron decreased over the period 1976 to 1980, with further total phosphorus decreases projected through 1982. Even greater decreases were projected in Lake Huron when Lake Michigan ice-cover-dependent setting velocities were applied, because this further reduced the loads from Lake Michigan into Lake Huron.

Direct measurement of ice cover effects on setting rates is needed to confirm the validity of the hypothesis that setting rates are dependent on ice cover extents. Annual surveillance of Lake Huron prior to stratification and after fall overturn would be needed to quantify the extent of ice-cover-induced effects on natural environmental variation of water quality. Annual surveillance would be useful for following total phosphorus trends and confirming the simple mass balance model's projected decreases based on loads and ice cover effects.

Conclusions

For periods of thermal stratification, a number of chemical differences between the epilimnion and hypolimnion were noted. TP, TDP, SRP, DRS, DNN, DA, and alkalinity were higher in the hypolimnion; whereas, conductivity and pH were higher in the epilimnion. The mean TDP, SRP, DRS, and DNN maximum depletions for 1980 were 30%, 56%, 35%, and 18.9%, respectively. During 1980, the average dissolved oxygen saturation was 99%.

For nearshore areas, 1980 Secchi disk depths, TN, DRS, sulfate, and conductivity were greater than those reported for 1974. Conversely, the 1980 TP and chloride concentrations were less than those reported for 1974.

Within the open lake, 1980 TP and DRS were less and DNN was greater than those reported for 1974. The decrease in TP followed a series of relatively colder winters. There was a 50% decrease in mean DRS and DNN maximum depletions in 1980 relative to those of 1974. Thus Lake Huron's trophic status appears to have improved between 1974 and 1980.

Regions of Lake Huron impacted by Lake Superior water had relatively low alkalinity, sodium, calcium, magnesium, and potassium concentrations. Conversely, regions impacted by Lake Michigan water had relatively high alkalinity, sodium, calcium, magnesium, and potassium concentrations. Regions measurably impacted by Lake Superior were confined primarily to the North Channel and Lake Huron waters adjacent to the western North Channel. Regions impacted by Lake Michigan were confined primarily to northern Lake Huron adjacent to the Straits of Mackinac and a region along the western shore of northern Lake Huron.

CHAPTER SIX

HOMOGENEOUS WATER MASSES - STATISTICAL APPROACH

by Russell Moll

Lake Huron is generally considered oligotrophic (IJC 1977, Schelske _et_ _al_. 1974). Low levels of dissolved nutrients and chlorophyll are found throughout most of the open lake. But, extensive lake-wide limnological surveys have shown large areal differences in many variables. Furthermore, the areal distribution of nutrients and chlorophyll changes considerably across different seasons. Moll _et_ _al_. (1976) used a multivariate statistical approach to identify regions of homogeneous water quality in the Straits of Mackinac region of Lake Huron. Berry (1980) used somewhat similar statistical techniques to define regions of homogeneous water quality in southern Lake Huron during the spring, summer, and fall of 1974. These two studies confirmed the same general hypothesis: although Lake Huron is an oligotrophic Great Lake, many regions of distinctly different water masses can be identified. These homogeneous water masses do not have a static areal location, but rather change position across seasons.

The motivation behind identifying homogeneous water masses in Lake Huron is twofold. First, the identification of the homogeneous water masses and their locations can broaden an understanding of how different water masses mix. By locating gradients between homogeneous water masses, inferences about water mass and nutrient exchanges can be developed. Second, seasonal or long-term trends of water quality in Lake Huron cannot be identified unless homogeneous water masses are compared across time.

The approach used in this chapter is to consider the identification of homogeneous water masses from a multivariate perspective. The areal distribution of variables considered one at a time was presented in Chapter Four. Lake Huron was then divided into many segments, and variables within individual segments were considered one at a time. The results from this segmented approach are presented in Chapter Five. Inferences about overall Lake Huron water mass distribution are difficult when multiple plots are considered. The multivariate approach has the benefit of identifying trends in the data which are reinforced by the fact that the trends occur in several variables as opposed to one variable (Pielou 1977).

Analytical Statistical Techniques

The statistical problem of developing homogeneous water masses comes under the general topic of statistical classification (Sneath and Sokal 1973). A variety of analytical methods is available to perform the classification, but they all require some degree of subjective interpretation. No statistical method yields a clear and precise separation between homogeneous water masses. As a consequence of this imperfect separation, several statistical techniques were used and the results compared for consistency. The underlying assumption of this approach was that, if true patterns exist in the areal distribution of water masses, the patterns should emerge with several analytical methods. Cluster analysis, principal components analysis, and discriminant functions analysis were the three analytical procedures used to define the homogeneous water masses. The analyses were conducted on a cruise-by-cruise basis for two reasons: 1) homogeneous water masses were not expected to have the same areal distribution among the six cruises, and 2) the large size of the database prevented analysis of all cruises at once. The analytical procedures are briefly described below.

Cluster Analysis — Cluster analysis attempts to develop hierarchial groupings of items in a multivariate mode (Sneath and Sokal 1973). The analytical approach used in cluster analysis does not require the data to follow any mathematical distribution. The items grouped (in this case, stations in Lake Huron) are simply compared for overall level of similarity and grouped according to some specific clustering algorithm. The choice of the clustering algorithm is somewhat arbitrary as are the interpretations of the results. One advantage of cluster analysis is that the technique will produce a logical, hierarchical grouping to the data even if such a grouping is not initially apparent.

The complete data set is displayed in the results, providing an evaluation of how all the items fit together into one hierarchical scheme. The major drawback to cluster analysis is that the technique will cluster any items into a hierarchical pattern irrespective of their true relationship. Random numbers can be successfully run through a clustering algorithm and produce reasonable results. A high level of critical judgment is required to interpret cluster analysis results. This disadvantage often requires a second statistical analytical procedure to confirm the cluster results.

The cluster analysis used to determine homogeneous water masses in Lake Huron was conducted as follows: Surface samples (1 m) were analyzed using five variables (temperature, conductivity, dissolved reactive silica, nitrate plus nitrite, and chlorophyll). The data were standardized before analysis, which requires subtracting the mean and dividing by the standard deviation for each of the five variables. Standardization has the effect of placing each variable in the same numerical range which makes them more intercomparable. The Euclidean distance between each variable was determined and the distance matrix was then used in the cluster analysis. The average-distance cluster algorithm was used to form clusters (Sneath and Sokal 1973). The results of the cluster analysis were checked by computing the cophenetic correlation coefficient, which is a measure of the association between the cluster results and the original data (Sneath and Sokal 1973). A high cophenetic correlation indicated the data conformed to the cluster results very well, while a low cophenetic correlation indicates a poor cluster result. In this study, all the cophenetic correlations were above 0.80. The results of the cluster analysis were displayed graphically by circling large, well-defined clusters of stations on Lake Huron (Figs. 6.1-6.6). Each cruise's water masses are labelled independently. Thus "a" for one cruise is not necessarily the same water mass as "a" for other cruises.

Principal Components Analysis -- Principal components analysis is a type of statistical ordination (Morrison 1978). This method begins with a correlation matrix among variables and reduces the number of original variables to one or two new variables. These new variables are called principal components and are composed from the original variables. The objective of this analysis is to produce two or three principal components which explain the correlation among these variables. The variable weights indicate how much each variable contributed to each principal component.

Principal components analysis has been extended in ecological applications to allow identification of groups of sampling sites (Pielou 1977). This grouping is achieved by the following computations: The principal component weights are multiplied by the value of each variable at each station and added at each station. The result is one number for each station for each principal component. This number is called a principal component score. Scores for principal component 1 (the most important component and the one that explains the most

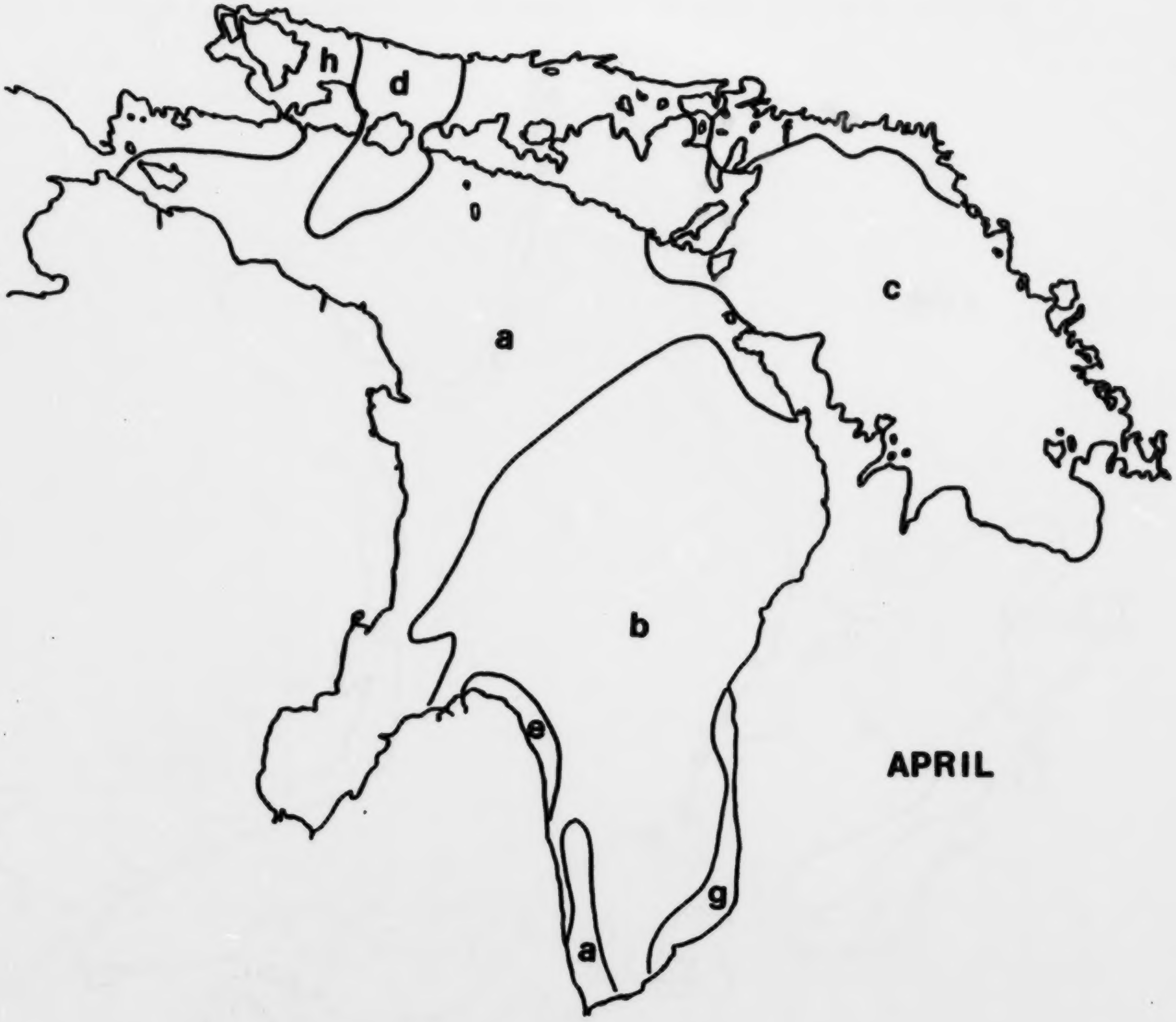

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Figure 6.1. Cruise 1 homogeneous water masses as defined by cluster analysis.

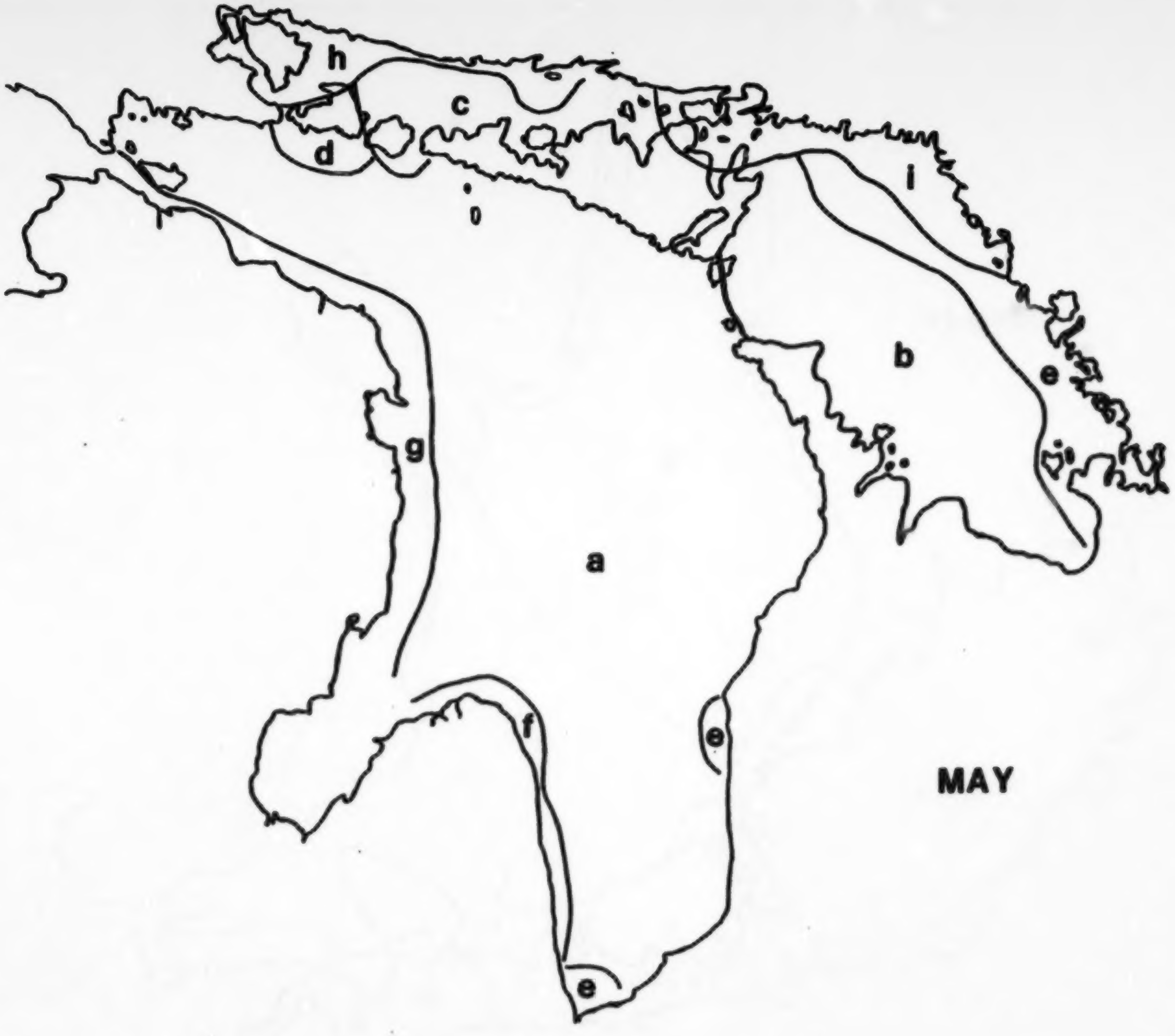
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Figure 6.2. Cruise 2 homogeneous water masses as defined by cluster analysis.

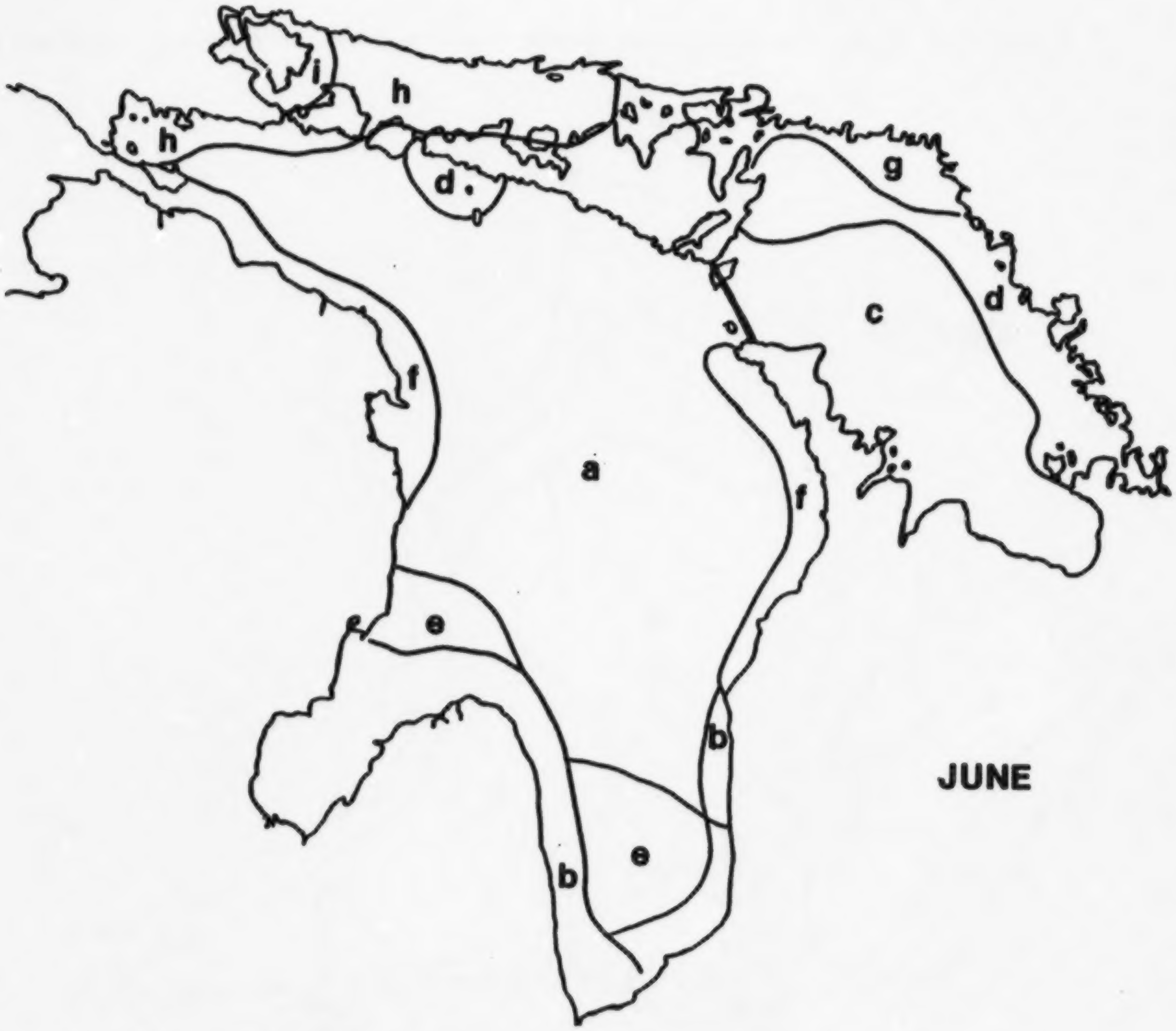
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Figure 6.3. Cruise 3 homogeneous water masses as defined by cluster analysis.

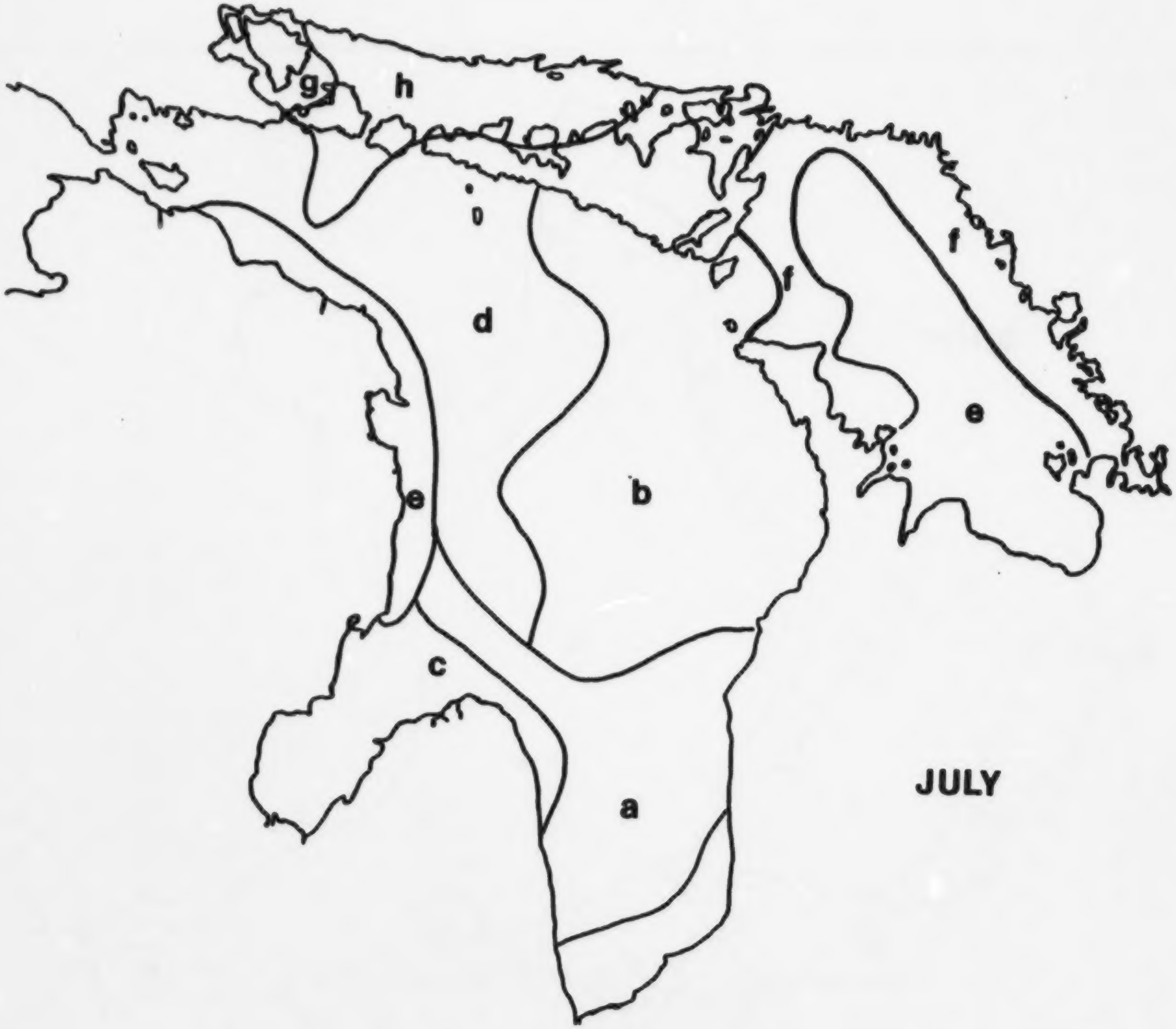
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Figure 6.4. Cruise 4 homogeneous water masses as defined by cluster analysis.

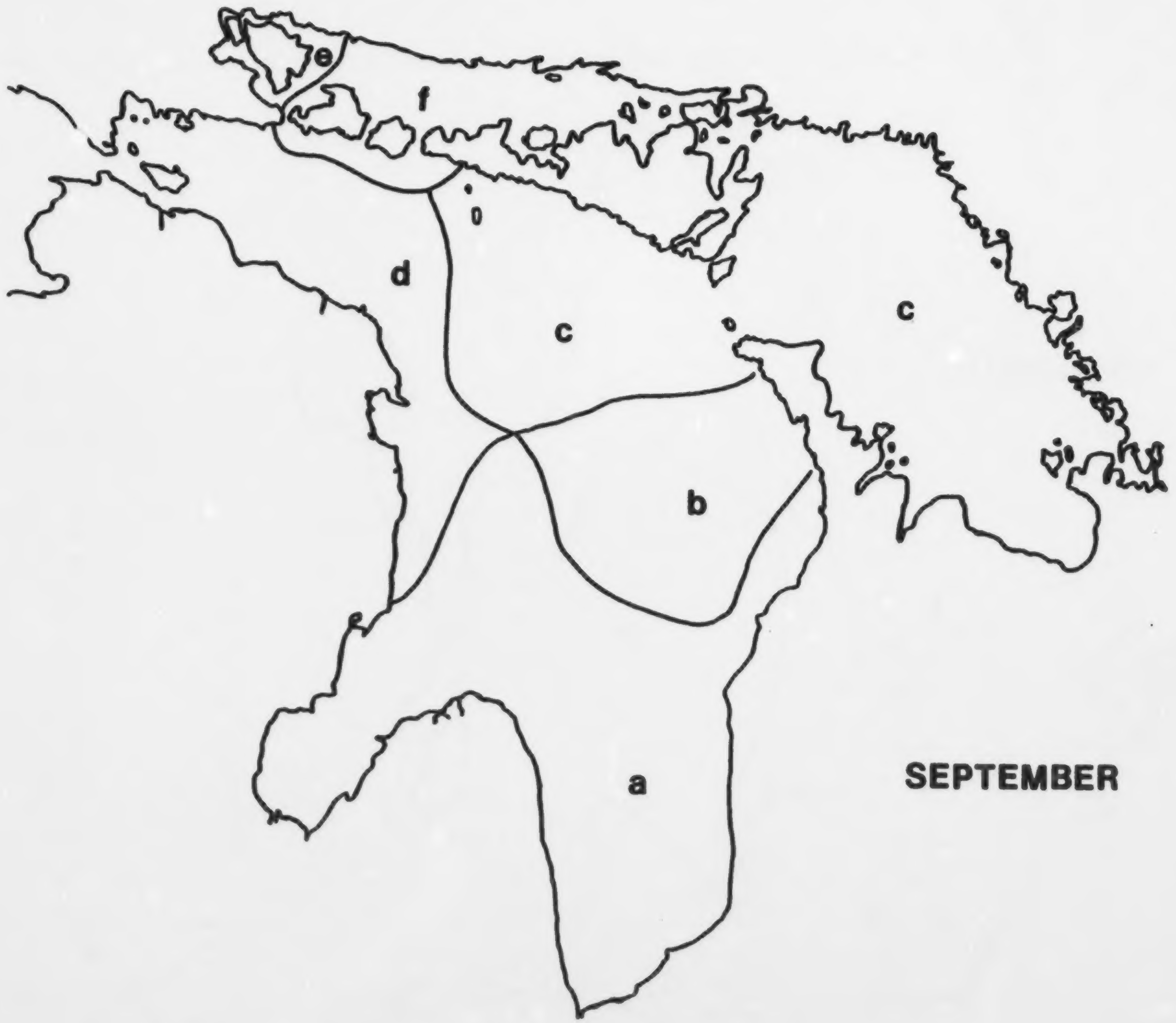
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Figure 6.5. Cruise 5 homogeneous water masses as defined by cluster analysis.

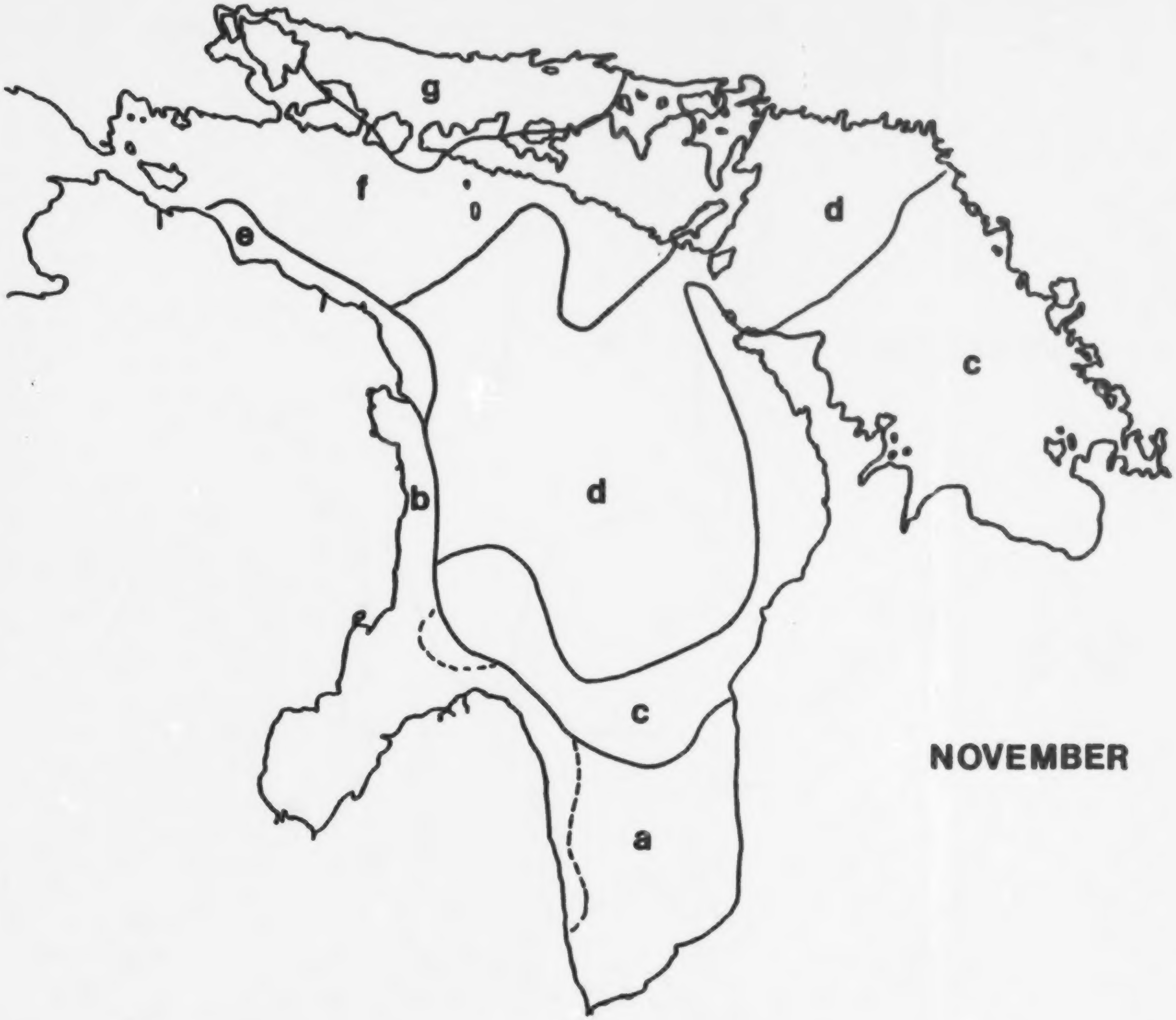
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Figure 6.6. Cruise 6 homogeneous water masses as defined by cluster analysis.

total variation) are plotted against scores for component 2 (second most important component). Stations which are highly similar will group together on this plot. A subjective decision is then made to determine if the groupings determined by principal components match the clusters determined by cluster analysis. This approach was used for each of the six Lake Huron 1980 cruises separately.

Discriminant Functions Analysis -- Discriminant functions analysis is used to confirm that identified groups or segments of data are statistically different from one another (Morrison 1978). Unlike the methods described above, discriminant functions analysis will not identify or suggest groups of data. Rather, the technique uses a multivariate method to compare variance-covariance structure among already identified groups. Thus, discriminant functions analysis is a logical next step beyond cluster analysis or principal components analysis; this analysis tests the hypothesis that the variance-covariance matrices for each identified group or cluster of stations are all equal to one another. If the hypothesis is rejected, the discriminant functions can then be applied to the original data and a new grouping determined. This new grouping is then compared to the original grouping, and differences are identified. The stations within the new grouping created by the discriminant function analysis are not identified, but rather, the number of stations which do not concur between the new (discriminant function result) and original groupings are tallied. A high (80% or better) concurrence between the new and original groupings indicates the classification supplied by the investigator was a fairly accurate appraisal of the true structure present in the data.

An analysis of the success of the original groupings scheme can be determined through calculation of the Goodman-Kruskal Tau statistic (Huberty 1975).

This statistic represents the reduction in overall within-group error from use of the original grouping scheme compared to chance (random) assignment. The Tau statistic is expressed as a fraction representing the proportion of reduction. A Tau value of 0.00 represents no reduction in the original grouping assignment over random assignment.

Non-Statistical Identification of Water Masses

Although a variety of statistical techniques are available to aid in the identification of homogeneous water masses, previously the most common approach has been intuitive geographic segmentation. This technique, which has proven to be surprisingly accurate, relies on one or more trained scientists to divide the lake(s) into homogeneous geographic regions. Despite the lack of statistical methods, this technique can substantially reduce within-group variance when conducted by an experienced limnologist. Lake Huron was the subject of several such intuitive segmentation schemes, one of which was used to evaluate lake-wide water quality from a 1974 database (IJC 1976) (Fig. 6.7). The results presented below compare the 1974 segmentation scheme to a 1980 geographic segmentation scheme (determined by the intuitive approach) and to the statistical segmentation determined by the cluster/principal component analysis.

Homogeneous Water Masses

The segmentation scheme developed from the 1974 study of Lake Huron and published in 1976 is shown in Figure 6.7. This scheme determined 19 open lake segments. Five segments covered the open lake regions as follows: northern basin; eastern southern basin; western southern basin-Saginaw Bay mouth;

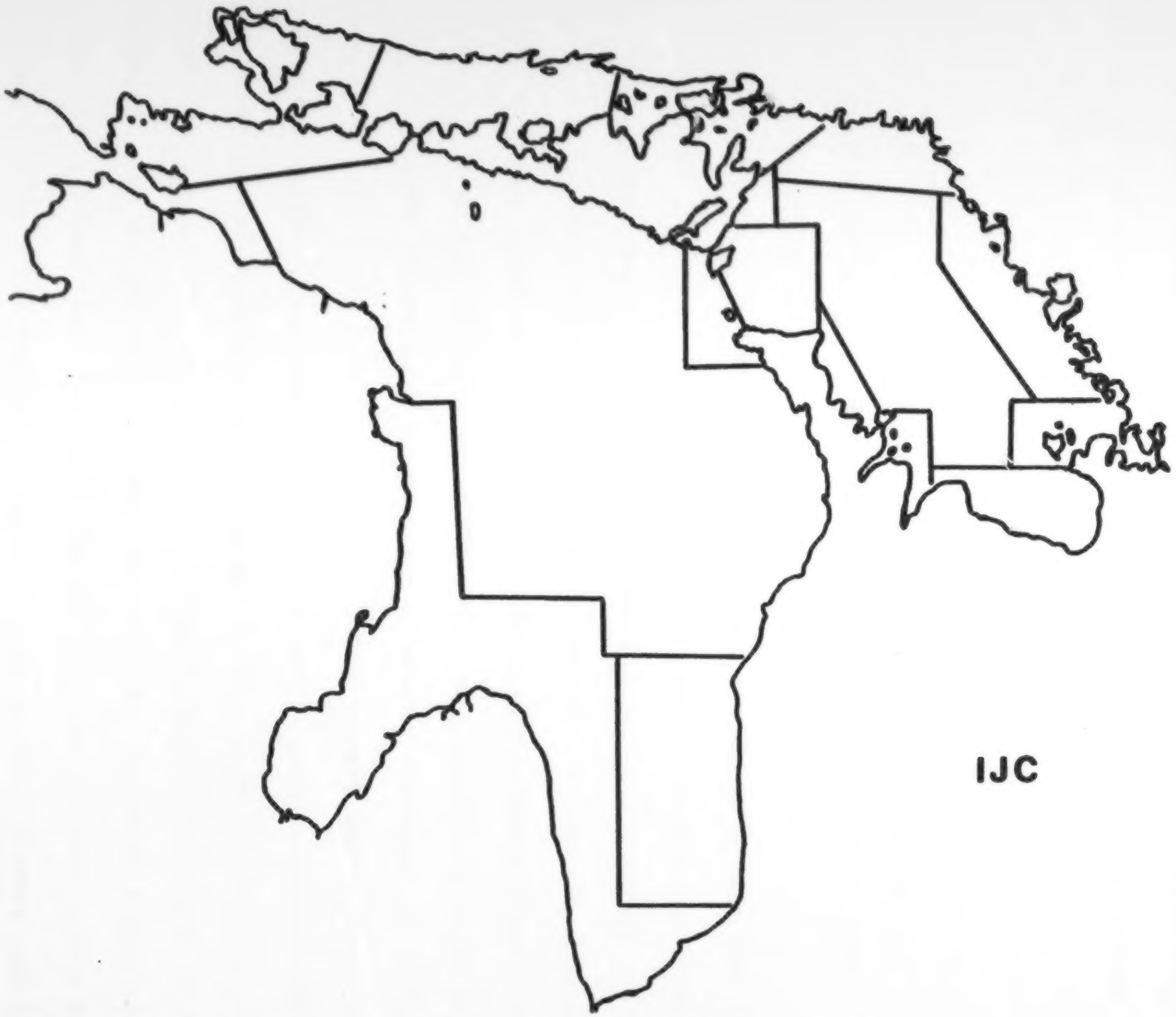

Figure 6.7. IJC segmentation scheme from 1974 Lake Huron study.

Georgian Bay; and North Channel. The remaining 14 segments are primarily nearshore. The advantages of this segmentation scheme are that it provides a high degree of resolution in determining spatial differences in water quality, and the segments have fixed boundaries based on the most reasonable separation of water masses. The disadvantages of this scheme are that the boundaries between segments are fixed and hence inflexible among seasons, and 19 segments may unnecessarily divide the lake into too many regions.

In an effort to counter the last criticism, that Lake Huron does not really have 19 distinct water masses, a second geographical segmentation scheme was devised (Fig. 6.8). This scheme has only 10 segments, with some stations not included in any segment (excluded from the analysis). The advantages of this scheme over the IJC scheme are a more logical division of Lake Huron based on geographic considerations, and fewer segments.

Both the IJC and second (future references to the second segmentation scheme will call this the EPA scheme) segmentation scheme divide the lake into segments based on distinct geographic regions: northern basin; southern basin; Saginaw Bay mouth; Georgian Bay; etc. This geographic definition of water mass boundaries is reasonable because it takes into account sources of water input into Lake Huron (see Chapter Four).

The IJC segmentation scheme (Fig. 6.7) identifies water masses in the Straits of Mackinac, western North Channel, western southern basin, and northern nearshore Georgian Bay (four segments). These segments are associated with inputs to Lake Huron from: Lake Michigan, Lake Superior, Saginaw Bay, and Canadian Shield rivers, respectively. The EPA segmentation scheme identifies segments in the same general areas as the IJC scheme, except nearshore Georgian Bay stations are not included. The major difference between the two segmentation

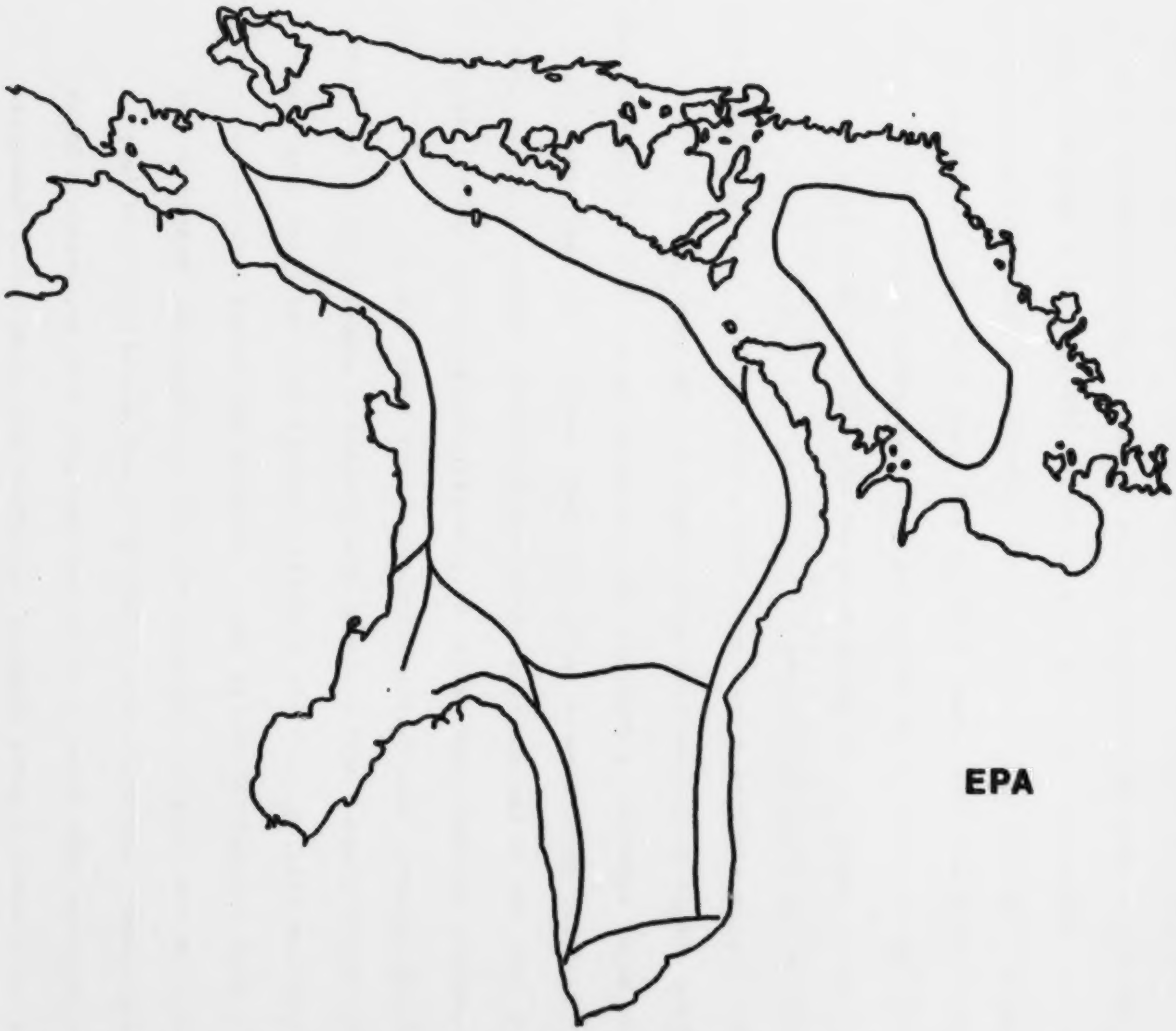

Figure 6.8. EPA segmentation scheme from 1980 Lake Huron study.

schemes is that the EPA scheme (Fig. 6.8) has fewer nearshore segments than the IJC scheme (Fig. 6.7).

The other approach used to determine homogeneous water masses was that of cluster analysis and principal components analysis. This multivariate approach has an advantage over the geographic method in that larger homogeneous water masses were identified, and hence Lake Huron was divided into a smaller number of segments than with either the IJC or EPA schemes. A further advantage is that the cluster analysis scheme does not set fixed water mass boundaries, but rather allows the location of boundaries to change among cruises. These changing boundaries appear to reflect more accurately the true water mass distribution than do the fixed boundaries.

The cluster analysis segmentation scheme for cruise 1 (Fig. 6.1) determined Lake Huron should be divided into eight segments. The open lake was divided into two major segments, a southern and a northern basin. Most of Georgian Bay formed the third major segment during the April cruise. The remaining five segments were all in the nearshore zones and included: eastern southern Lake Huron; western southern Lake Huron: northwestern Georgian Bay; central North Channel and adjacent Lake Huron; and northwestern North Channel.

The second cruise (May) analysis also yielded a segmentation scheme with eight clusters (Fig. 6.2). This analysis produced only one major open lake segment which covered the entire lake. Georgian Bay formed a second major segment. The remaining six segments were all nearshore and located in the following areas: western northern Lake Huron and eastern Georgian Bay; western southern Lake Huron; northwestern Georgian Bay; southeastern North Channel; northwestern North Channel; and DeTour and False DeTour passages.

The third cruise was conducted in early June 1980 and the analysis produced nine homogeneous segments (Fig. 6.3). Similar to the May results, one large homogeneous water mass was identified in open Lake Huron, and another segment covered most of Georgian Bay. The remaining seven segments were composed of several disjointed nearshore segments. These nearshore segments were as follows: the mouth of Saginaw Bay and eastern and western southern Lake Huron; open southern Lake Huron and north of Saginaw Bay mouth; northeastern Georgian Bay; northwestern Georgian Bay; northern Straits of Mackinac and central North Channel; western North Channel; and northern, eastern, and western northern Lake Huron.

The fourth research cruise was conducted in July 1980 and yielded a segmentation scheme (Fig. 6.4) that differed considerably from the first three cruises. Eight homogeneous water masses were identified, but most of these eight were offshore segments rather than nearshore segments. The only nearshore segments are: the mouth of Saginaw Bay and adjacent western southern Lake Huron; western North Channel; and northern and western Georgian Bay. The remaining five segments included open Lake Huron as follows: southern Lake Huron; eastern northern Lake Huron; western northern Lake Huron; North Channel and adjacent Lake Huron; and Georgian Bay and nearshore western Lake Huron.

The analysis of the fifth (September) cruise yielded a segmentation scheme with only six homogeneous water masses (Fig. 6.5). The only nearshore segment was extreme eastern and western North Channel. Central North Channel and adjacent Lake Huron composed another homogeneous water mass. The remaining four segments roughly divided Lake Huron into geographic quadrants. These quadrants were: southern and central Lake Huron; eastern Lake Huron; Georgian Bay and adjacent Lake Huron; and northwestern Lake Huron.

The November cruise segmentation scheme divided Lake Huron into seven homogeneous water masses (Fig. 6.6). Similar to the previous cruise, only one nearshore segment was identified in northwestern Lake Huron. The remaining six open lake segments were distributed as follows: North Channel and adjacent Lake Huron; northwestern Lake Huron and eastern North Channel; western Georgian Bay and central Lake Huron; eastern Georgian Bay and south central Lake Huron; and southern Lake Huron and the mouth of Saginaw Bay (constitutes two complex segments).

The representation of homogeneous water masses is only approximate because several water masses are not easily represented on a map of Lake Huron. Figures 6.1-6.6 show only the approximate location of the boundaries of homogeneous water masses. Table 6.1 gives the station numbers which compose each homogeneous water mass. This table shows that occasionally one Georgian Bay station may group with a geographically distant water mass (cruise 1, segment eight, for example). But, the vast majority of homogeneous water masses were geographically compact.

Discriminant Functions Analysis

The results of the cluster analysis and principal components analysis yielded substantially different homogeneous water masses than the geographic procedure used in the past. Linear Discriminant Function Analysis was used to confirm if the segmentation scheme developed by the cluster analysis was statistically significant, i.e., the differences among segments were statistically significant using five variables. The Discriminant Analysis was applied to the IJC, EPA, and cluster analysis segmentation schemes in the same fashion so the three schemes could be compared.

Table 6.1. Homogeneous water masses determined by cluster analysis/principal components analysis.

Water Mass	Stations
	Cruise 1
1	1, 8, 10, 18-20, 22-23, 25, 34-36, 41, 44-49, 51-56, 61, 62, 65, 66
2	2, 6, 9, 12, 15-16, 21, 24, 26, 27, 42, 43, 90-93
3	50, 101-124, 126, 128-137, 139-140
4	13, 14, 17, 63
5	64, 67, 125, 138, 141-144
6	3-5, 11
7	68-72, 127
8	57-58, 60, 75-77
	Cruise 2
1	1, 11, 13, 22-23, 25, 34-36, 41, 46-47, 55-56, 63-64, 105, 108, 110, 115-116, 128, 139, 141-142
2	2, 6, 8-9, 12, 15-16, 18-21, 24, 26-33, 37-39, 43-45, 48-54, 57, 59, 61-62, 65-66, 90-93
3	101-104, 106-107, 111-114, 117-122, 129-136, 140
4	58, 73-78, 80, 82-83, 85-86
5	60, 67, 79, 87, 89
6	7, 10, 14, 40, 94
7	68-72, 81, 84
8	88, 109, 123-127, 138, 143, 144

(Continued)

Table 6.1. Continued.

Water Mass	Stations
	Cruise 3
1	1-2, 7-8, 10-11, 13-14, 16-20, 22, 94
2	6, 21, 23-25, 50, 90-91
3	101-103, 106-107, 111-114, 117-122, 129-135
4	104, 105, 108, 110, 115-116, 123-124, 128, 136-137, 139-142
5	9, 12, 15, 26-27, 29, 31-33, 37-38, 43, 45, 48-49, 51-54, 57, 61, 66, 92-93
6	28, 30, 35, 39-42, 46-47, 55-56, 58-59, 62-64
7	65, 67, 70, 72-78, 80-86
8	68, 69, 71
9	87-89, 109, 125-127, 138, 143-144
	Cruise 4
1	6-7, 9-12, 15-16, 24, 26, 28, 33, 90-94
2	23, 25, 34-35, 41, 46-47, 55-56, 62, 101-108, 111-112, 114, 117, 119-120, 122, 128-130, 137, 139
3	13-14, 17-18, 20, 22, 113, 118, 121
4	17, 19-32, 37, 39-40, 42, 45, 49-54, 59 59, 133-135
5	109-110, 115-116, 123-127, 136, 138, 140-142
6	57, 60, 73-87
7	38, 68, 69, 70

(Continued)

Table 6.1. Concluded.

Water Mass	Stations
	Cruise 5
1	1-21, 24, 26-28, 30, 33, 37, 39, 90-94
2	25, 34-35, 46-47, 54-57, 61, 63, 65-66, 125, 142
3	29, 31-32, 38, 40-41, 43
4	42, 44-45, 48-49, 51-53, 59, 101-108, 110-124, 126-141
5	58, 60, 67, 70, 72-79, 81-85
6	71, 80, 86-89
	Cruise 6
1	1-6, 8-11, 18, 20-22, 90-92
2	7, 13-14, 19, 23, 25, 34-36, 109
3	15-16, 24, 26, 28, 30-31, 33,39, 40-42, 49, 93, 101-108, 110-124, 131
4	27, 29, 32, 37-38, 43-45, 52-53, 125-130, 132-142
5	46-47, 55-56, 62, 65
6	48, 50-51, 54, 57, 59-61, 66-68
7	58, 70-86

The initial hypothesis tested in Discriminant Analysis was that all the different segments have the same variance-covariance matrix versus the variance-covariance matrices were not equal. For all cruises for each of the three segmentation schemes this hypothesis was rejected and the alternate hypothesis that the variance-covariance matrices were not equal was accepted. The inference from these results was that distinctly different homogeneous water masses were identified. This analysis was carried an additional step by examining the amount of reduction in the variance-covariance matrices for each segmentation scheme for each cruise. The results are shown in Table 6.2 as represented by the Goodman-Kruskal Tau statistic. The larger the statistic, the larger the reduction of the within-group (within-segment) variance and hence statistically more distinct homogeneous water masses. Table 6.2 confirms that all three segmentation schemes yielded some reduction of the within-group variance over random assignment of stations to segments. The cluster analysis/principal components analysis approach consistently produced the most reduction in within-group variance, while the IJC scheme yielded the least reduction of variance.

Table 6.2. Goodman-Kruskal Tau statistics for each cruise for the three different homogeneous water mass schemes. Number of water masses are shown in parentheses behind each Tau statistic.

	IJC	EPA	Cluster
April	.4794 (18)	.5318 (10)	.7994 (8)
May	.4470 (18)	.6576 (10)	.9091 (8)
June	.5925 (18)	.6301 (10)	.8527 (9)
July	.4092 (18)	.5846 (10)	.6234 (7)
September	.4852 (18)	.6738 (10)	.7515 (6)
November	.5450 (18)	.7025 (10)	.8951 (7)

Homogeneous Water Masses - Ecological Inferences

The primary motivation behind identifying homogeneous water masses is to determine if the water body has spatial structure across several variables, and what is the nature of that spatial structure. For a body of water such as Lake Huron, identification of spatial structure is not surprising since such a large lake cannot be completely mixed both vertically and horizontally. The input of several different water types into Lake Huron is a major source of spatial variability (IJC 1976). Anthropogenic loadings in the nearshore zone contribute further to spatial inhomogenities (Davis et al. 1980).

The IJC and EPA segmentation schemes (Figs. 6.7 and 6.8) recognized these different inputs to Lake Huron and developed a segmentation scheme accordingly. But, these schemes lack flexibility. Anthropogenic inputs, nutrient loadings, nutrient utilization, etc. all have seasonal components based on physical and biological events. These events can lead to large changes in the spatial distribution of a suite of variables and thus change the shape, size, and distribution of homogeneous water masses. Furthermore, long-term changes in nutrient loadings can have a major effect on spatial water mass distribution. Examples of physical events which can affect water mass distribution would be formation and migration of the thermal bar, thermocline formation, upwelling, and large amplitude internal waves. Biological events which readily affect water mass composition include intense primary production in algal blooms, vertical migration by zooplankton, and anaerobic decomposition in the benthos. Mitigating measures (sewage treatment) also have important effects on nutrient loadings and distribution. The net result is that the distribution of homogeneous water masses in any large lake will not be static but rather dynamic based on a combination of physical and biological events. The geographic approach used in the past cannot accommodate the dynamic nature of the lake because water mass boundaries are not static. The statistical approach described above does accommodate this dynamic aspect of Lake Huron.

The segmentation scheme determined by the cluster analysis/principal components analysis yielded results which indicated the influence of thermal bar conditions and thermal stratification. The first three cruises were conducted during thermal bar conditions. These conditions are characterized by a well-mixed, homothermous open lake, and a warmer, thermally stratified nearshore zone (Boyce 1974). Because thermal bar conditions occur during periods of high spring runoff, nutrient concentrations near shore are often elevated (Davis *et al*. 1980). The segmentation scheme developed by the statistical approach reflected the development and progression of the thermal bar.

The April segmentation scheme (Fig. 6.1) shows only a few nearshore segments, with the two largest of these in the southern basin. During April 1980, thermal bar conditions were just beginning in the southern end of Lake Huron.

The thermal bars rapidly developed between the first (April) and second (May) cruises. This development includes both the movement of the bar offshore as well as development of thermal bars in the northern basin (Boyce 1974, Scavia and Bennett 1980). The segmentation scheme accurately reflects these physical conditions; the segmentation scheme from the May cruise included long nearshore segments in both the northern and southern basins (Fig. 6.2). Some of the May nearshore segments were much wider than the corresponding April segment, i.e., northern Georgian Bay.

Thermal bar conditions continued through the third cruise (June). The segmentation scheme reflects these physical conditions with large, wide nearshore segments around all of Lake Huron (Fig. 6.3). In addition, the central southern basin is in a separate segment from the remaining open lake. This segment accurately reflects the onset of thermal stratification throughout the lower southern basin.

Lake Huron became completely thermally stratified between the third and fourth (July) cruises. This change in the physical status of the lake induced a large change in the spatial location of homogeneous water masses. Rather than a well-mixed, uniform open lake, large water masses were found throughout the entire lake (Fig. 6.4). Nearshore segments did not account for most of the segments as in the first three cruises. Furthermore, the open lake segments were not strictly divided by east-west or north-south boundaries as are often used in geographic segmentation, but rather were complex and somewhat meandering boundaries.

The boundaries between the July water masses were less distinct than for the three earlier cruises. In July, subtle differences in nutrient concentrations were the basis of the different water masses. Earlier in the year, sharp contrasts in nutrient concentrations across the thermal bar were the basis for distinguishing different water masses. As a result, the homogeneous water masses identified by the multivariate techniques were a more accurate representation of true conditions in Lake Huron for the first three cruises than for cruise 4. The Tau statistics in Table 6.2 reflect the change from cruise 3 to cruise 4; the statistics for cruises 1 through 3 were .799, .909, and .853, respectively, while the statistic for cruise 4 was .623.

These results suggest the rather complex distribution of nutrients, chlorophyll, and conductivity in Lake Huron. Physical factors such as currents, depth of thermocline, etc. were probably an important mechanism in determining the distribution of the homogeneous water masses. This hypothesis is further supported by the concept that the plankton, which are passive floaters, are the major biological group affecting open lake nutrient concentrations. Therefore, the results indicate that physical processes appear strongly to influence the location of homogeneous water masses while the composition and abundance of the plankton affect nutrient concentrations within homogeneous water masses.

The fifth cruise was conducted in September with Lake Huron remaining thermally stratified. The segmentation scheme (Fig. 6.5) yielded the lowest total number of segments of the six cruises (six segments) and the lowest number of nearshore segments (one). These results also support the hypothesis that the shape and distribution of homogeneous water masses originates primarily from physical mixing events. In September, Lake Huron appeared to be well mixed in a horizontal plane, but highly variable (stratified) in the vertical plane.

The sixth cruise was conducted in mid-November when Lake Huron was in the transition between thermally stratified and winter homothermous. Under these conditions, a deep thermocline exists only in the middle of the lake. Nearshore zones are relatively warm and homothermous (see Chapter Three). The segmentation scheme for cruise 6 (Fig. 6.6) resembles a mixture of the pre- and post-thermal bar schemes; there are some nearshore segments, but also some irregularly shaped open lake segments.

Two segments deserve particular attention because of previous research. In 1973, a long homogeneous water mass was observed along Lake Huron's western shore from the Straits of Mackinac to Thunder Bay (Moll _et al_. 1976). This water mass was interpreted to represent Lake Michigan water entering Lake Huron through the Straits of Mackinac. This same homogeneous water mass was observed in three of the six cruises (2, 3, and 6). The other homogeneous water mass of historical interest was also a long segment on Lake Huron's western shore. In 1974 this segment was observed running from the mouth of Saginaw Bay around the "Thumb" of Michigan and into the southern basin. This water mass was interpreted to represent Saginaw Bay water flowing into Lake Huron. This segment was only observed during the first three cruises of 1980, and was only partially present during cruise 1.

Homogeneous Water Masses - Statistical Inferences

The segmentation scheme developed by the cluster analysis/principal components analysis consistently yielded fewer segments with a larger reduction in variance than the geographic segmentation scheme (Table 6.3). This result can be used to advantage in analysis of data and development of experimental designs for further monitoring. The analysis of data is improved with fewer segments by way of decreasing the within-group variance. Since the smallest number of homogeneous water masses were identified with the cluster analysis/principal components analysis approach, each water mass, on the average, will have a larger number of stations. This larger number of stations will reduce the variance. As a result of the smaller within-segment variances, the statistical power in determining differences among water masses is increased (Lindgren 1976, Sokal and Rohlf 1969). Table 6.3 shows that the confidence intervals were usually smallest for all cruises using the cluster analysis/principal components analysis approach versus the geographic approach. The reduction in confidence

Table 6.3. Number of samples (N), means, and 95% confidence intervals for soluble silica, nitrate plus nitrite, and chlorophyll for each of the three homogeneous water mass schemes.

	N	Mean	Confidence Interval
Northern Basin -- July			
IJC			
Silica	131	1.301	.066
Nitrate	130	.268	.004
Chlorophyll	78	1.305	.105
EPA			
Silica	84	1.428	.080
Nitrate	83	.277	.005
Chlorophyll	42	1.505	.119
Cluster			
Silica	103	1.226	.068
Nitrate	102	.266	.004
Chlorophyll	56	1.200	.083
Southern Basin -- April			
IJC			
Silica	36	1.481	.014
Nitrate	36	.332	.027
Chlorophyll	19	2.347	.297
EPA			
Silica	28	1.510	.018
Nitrate	28	.283	.005
Chlorophyll	8	1.738	.161
Cluster			
Silica	62	1.491	.012
Nitrate	62	.281	.004
Chlorophyll	19	1.658	.100
Georgian Bay -- November			
IJC			
Silica	44	1.247	.031
Nitrate	44	.277	.004
Chlorophyll	12	1.108	.096
EPA			
Silica	44	1.247	.031
Nitrate	44	.277	.004
Chlorophyll	12	1.108	.096
Cluster			
Silica	146	1.248	.038
Nitrate	146	.273	.003
Chlorophyll	50	1.232	.052

intervals is especially important in the nearshore segments. In these segments, the geographic approach yields too many segments with very large variances because of the small sample sizes. The cluster analysis/principal components analysis tends to remove the problem by having fewer segments with larger sample sizes.

The inference for improved experimental design originates from more efficient sample station location. Parsimonious placement of sampling stations for a lake-wide monitoring program would dictate at least three stations per homogeneous water mass. The IJC segmentation scheme would therefore require at least 54 stations, while the cluster analysis scheme would require from 18 to 27 stations. In practice, it is unlikely a sampling grid could be tailored precisely to any segmentation scheme; the identification of segments by the cluster/principal component analysis approach cannot be achieved until after the samples have been collected. But, if a sampling grid of approximate uniform station density were developed (such as for 1980), the segmentation scheme may aid in judicious choice of sample analysis. For example, phytoplankton cell counts are normally counted long after the samples are collected. Given a desire to count three samples from each segment, fewer segments means less counting.

Finally, identification of homogeneous water masses is an important step for long-term trend analysis. Only by comparing similar water types can trends be examined across years. Because the cluster/principal components analysis approach shows that homogeneous water masses change considerably among seasons, long-term trends should be inferred only from similar water types in similar seasons. Without such an approach, the statistical power in resolving long-term trends will be very low. These statistical concepts are used in Chapter Eight to develop long-term trends in Lake Huron water quality.

CHAPTER SEVEN

STATISTICAL INFERENCES: LAKE HURON, 1980

By Russell Moll

The surveillance and study of Lake Huron in 1980 yielded a large, extensive database. The geographical area studied during the six cruises from April to November produced a large range in many of the measured variables (Table 7.1). Complete ecological interpretation of the Lake Huron data was not possible by non-statistical methods alone, i.e., data plots and contour maps. For example, Chapter Four, the descriptive physical-chemical limnology of Lake Huron, was restricted to comparisons among surface samples and vertical profiles of only one station for each of the major basins. The purpose of this chapter is to invoke several statistical analytical methods to expand the inferences about Lake Huron from the 1980 database. The techniques presented below have been used before in ecological studies (Langbein and Lichtman 1978).

The results presented in Chapter Four had two shortcomings which were somewhat removed by the statistical approach used below. These shortcomings were: the data were analyzed only at one depth or for one station at a time, and comparisons among cruises were limited. The multivariate techniques presented below were used to take large, complex databases and reduce the data into a smaller database or into one meaningful statistic. By reducing the database, ecological inferences were more apparent.

Statistical Methods

Two groups of statistical techniques were used to yield broader inferences from the 1980 Lake Huron data: correlation analyses and tests of multivariate

Table 7.1. Complete list of chemical and physical variables measured during 1980 Lake Huron study.

Alkalinity
Ammonia
Chlorophyll
Dissolved Oxygen
Kjeldahl Nitrogen
Particulate Organic Carbon
Particulate Organic Nitrogen
pH
Secchi Depth
Soluble Nitrate-Nitrogen
Soluble Reactive Phosphorus
Soluble Reactive Silica
Specific Conductance
Temperature
Total Filterable Phosphorus
Total Phosphorus
Transmissivity
Turbidity

hypotheses. The computations were performed using The University of Michigan statistical software package MIDAS (Fox and Guire 1976). Correlation, unless otherwise specified, refers to the simple Pearson Product-Moment zero-order correlations (Sokal and Rohlf 1969). The data set is not totally balanced and has some missing observations. As a result of these empty or missing cells, all zero-order correlations were computed with a missing-data algorithm. In effect, all pairs of observations were used to calculate each correlation coefficient, not just pairs from complete cases (Fox and Guire 1976). Computation of higher-order correlations and factor analysis required complete cases.

Factor analyses were conducted for each cruise using the complete-case correlation matrices. The number of factors extracted per cruise was based on the Scree Test (Kim and Mueller 1978). Five factors were extracted for cruises 1, 2, 5, and 6, four factors for cruise 3, and three factors for cruise 4. The values of the communalities were estimated using the iterative principal axis factor solution as described in Harman (1967). Convergence of communalities was deemed sufficient when succeeding estimates differed by less than 0.001, or after twenty iterations. An orthogonal varimax rotation was performed on the factor matrix (Kim and Mueller 1978).

Results

Correlation Analyses

The correlation analyses were conducted in a three-step procedure. First, zero-order correlations were calculated among all pairs of variables. The results of calculations were used to reduce the number of variables analyzed by removing highly correlated, and thus somewhat redundant, variables. Second, a reduced data set was composed of 10 variables (Table 7.2) which represented a non-redundant data set. A factor analysis was conducted on the reduced correlation matrix for each cruise. Third, results from each cruise were compared to one another to determine seasonal changes in relationships among variables.

The correlation matrices show a high, positive correlation for all six cruises among chloride (Cl), conductivity (Cond), and alkalinity (Alkal). These correlations were all highly significant at the $P < .01$ level. The values of these correlations ranged from 0.821 to 0.966. A further indication of the somewhat redundant nature of these three variables was the similar correlations

Table 7.2. Reduced set of variables used in multivariate analysis.

Temperature
Specific Conductance
pH
Soluble Nitrate-Nitrogen
Soluble Reactive Phosphorus
Soluble Reactive Silica
Ammonia
Total Phosphorus
Total Filterable Phosphorus
Kjeldahl Nitrogen

among chloride, conductivity, and alkalinity to other variables. For example, the Cl to total phosphorus correlations ranged from -0.081 to 0.155 across cruises; the conductivity to total P correlations ranged from -0.148 to 0.043; the alkalinity to total P correlations ranged from -0.186 to 0.025. Likewise, the correlations among ammonia (NH_3) and chloride, conductivity, and alkalinity were similar in magnitude and seasonal response. Table 7.3 gives the correlations among chloride, conductivity, alkalinity, total P, and NH_3. These results indicated that the three variables provided approximately the same ecological inference.

A similar type of analysis determined a high level of redundancy between (or among) the following sets of variables: chloride to alkalinity to conductivity to sulfate; particulate organic carbon to particulate organic nitrogen; unfiltered ammonia to filtered ammonia; unfiltered soluble nitrate plus nitrate to filtered soluble nitrate plus nitrite. The highly correlated pairs or sets of variables listed above do not become decoupled across seasons. These results

Table 7.3. Cruise 1 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	72.898	8.3331	435	.9749	91.025	0.
11.CONDUCTI	193.67	21.352				
10.ALKALINI	72.137	8.6551	378	-.6373	-16.034	.0000
17.NH3	.32354 -2	.50183 -2				
10.ALKALINI	72.718	8.3812	403	-.0445	-.89263	.3726
26.TOTAL P	.57385 -2	.41385 -2				
11.CONDUCTI	191.89	22.262	378	-.6321	-15.816	.0000
17.NH3	.32354 -2	.50183 -2				
11.CONDUCTI	193.33	21.590	403	-.0226	-.45365	.6503
26.TOTAL P	.57385 -2	.41385 -2				
17.NH3	.33526 -2	.52251 -2	346	.2989	5.8100	.0000
26.TOTAL P	.56289 -2	.36328 -2				

Table 7.3. Cruise 2 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	72.453	8.5115	502	.9600	76.615	0.
11.CONDUCTI	190.57	22.166				
10.ALKALINI	72.802	8.5160	456	.8416	33.205	0.
21.CHLORIDE	5.0923	.84531				
10.ALKALINI	72.374	8.5828	491	-.4698	-11.770	.0000
16.NH3	.25418 -2	.34262 -2				
10.ALKALINI	72.415	8.5032	500	-.1856	-4.2152	.0000
23.TOTAL P	.51774 -2	.14927 -2				
11.CONDUCTI	191.39	22.554	457	.8885	41.302	0.
21.CHLORIDE	5.0919	.84443				
11.CONDUCTI	190.36	22.329	492	-.4030	-9.7475	.0000
16.NH3	.25407 -2	.34228 -2				
11.CONDUCTI	190.46	22.110	501	-.1483	-3.3509	.0009
23.TOTAL P	.51756 -2	.14917 -2				
21.CHLORIDE	5.0837	.85147	447	-.2492	-5.4282	.0000
16.NH3	.25414 -2	.35520 -2				
21.CHLORIDE	5.0868	.84089	455	.0049	.10337	.9177
23.TOTAL P	.52121 -2	.15116 -2				
16.NH3	.25429 -2	.34296 -2	490	.2410	5.4849	.0000
23.TOTAL P	.51741 -2	.15015 -2				

Table 7.3. Cruise 3 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	73.785	8.3941	543	.9192	54.288	0.
11.CONDUCTI	194.46	21.671				
10.ALKALINI	73.809	8.3947	544	.8209	33.461	0.
19.CHLORIDE	5.1206	.76946				
10.ALKALINI	73.694	8.3280	540	-.3010	-7.3210	.0000
14.NH3	.27759 -2	.28251 -2				
10.ALKALINI	73.807	8.3871	545	-.0697	-1.6288	.1039
21.TOTAL P	.46552 -2	.11504 -2				
11.CONDUCTI	194.47	21.691	542	.9334	60.437	0.
19.CHLORIDE	5.1192	.77053				
11.CONDUCTI	194.19	21.550	538	-.1688	-3.9658	.0001
14.NH3	.27732 -2	.28299 -2				
11.CONDUCTI	194.46	21.671	543	.0072	.16818	.8665
21.TOTAL P	.46552 -2	.11525 -2				
19.CHLORIDE	5.1124	.76732	539	-.0496	-1.1511	.2502
14.NH3	.27774 -2	.28275 -2				
19.CHLORIDE	5.1206	.76946	544	.0602	1.4048	.1607
21.TOTAL P	.46575 -2	.11502 -2				
14.NH3	.27759 -2	.28251 -2	540	.2140	5.0822	.0000
21.TOTAL P	.46567 -2	.11545 -2				

Table 7.3. Cruise 4 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	73.459	8.2832	673	.9656	96.144	0.
11.CONDUCTI	190.69	19.144				
10.ALKALINI	74.042	7.9599	478	.8782	40.057	0.
19.CHLORIDE	5.1174	.75999				
10.ALKALINI	73.459	8.2827	673	.0556	1.4428	.1495
14.NH3	.48945 -2	.36309 -2				
10.ALKALINI	73.459	8.2827	673	.0245	.63587	.5251
21.TOTAL P	.49565 -2	.16008 -2				
11.CONDUCTI	191.83	18.953	479	.9130	48.883	0.
19.CHLORIDE	5.1171	.75921				
11.CONDUCTI	190.67	19.138	673	.0313	.81165	.4173
14.NH3	.49004 -2	.36278 -2				
11.CONDUCTI	190.67	19.138	673	-.0427	-1.1066	.2689
21.TOTAL P	.49572 -2	.16013 -2				
19.CHLORIDE	5.1171	.75921	479	.0637	1.3943	.1639
14.NH3	.51754 -2	.37482 -2				
19.CHLORIDE	5.1171	.75921	479	-.0810	-1.7740	0767
21.TOTAL P	.50305 -2	.17356 -2				
14.NH3	.48947 -2	.36283 -2	674	.2989	8.1189	.0000
21.TOTAL P	.49583 -2	.16003 -2				

Table 7.3. Cruise 5 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	74.418	6.2588	593	.9175	56.094	0.
11.CONDUCTI	187.11	14.397				
10.ALKALINI	74.353	6.3230	597	.8501	39.368	0.
19.CHLORIDE	5.1802	.54706				
10.ALKALINI	74.356	6.3181	598	.0929	2.2771	.0231
14.NH3	.16689 -2	.19085 -2				
10.ALKALINI	74.356	6.3181	598	-.0527	-1.2877	.1984
21.TOTAL P	.47669 -2	.12344 -2				
11.CONDUCTI	187.08	14.403	594	.8789	44.831	0.
19.CHLORIDE	5.1850	.53752				
11.CONDUCTI	187.08	14.391	595	.1173	2.8754	.0042
14.NH3	.16622 -2	.19003 -2				
11.CONDUCTI	187.08	14.391	595	.0431	1.0500	.2941
21.TOTAL P	.47555 -2	.12301 -2				
19.CHLORIDE	5.1793	.54641	599	.0921	2.2595	.0242
14.NH3	.16678 -2	.19071 -2				
19.CHLORIDE	5.1793	.54641	599	-.0800	-1.9617	.0503
21.TOTAL P	.47661 -2	.12333 -2				
14.NH3	.16667 -2	.19057 -2	600	.1770	4.3967	.0000
21.TOTAL P	.47638 -2	.12335 -2				

Table 7.3. Cruise 6 missing data correlations for 1980.

VARIABLE	MEAN	STD DEV	N	CORR	T-STAT	SIGNIF
10.ALKALINI	75.192	7.1858	474	.9479	64.674	0.
11.CONDUCTI	201.04	17.402				
10.ALKALINI	75.265	7.1704	480	.9176	50.475	0.
19.CHLORIDE	5.2712	.65656				
10.ALKALINI	75.274	7.1661	481	.1231	2.7141	.0069
14.NH3	.25696 -2	.16720 -2				
10.ALKALINI	75.274	7.1661	481	.0325	.71204	.4768
21.TOTAL P	.52241 -2	.14682 -2				
11.CONDUCTI	201.02	17.413	473	.9593	73.699	0.
19.CHLORIDE	5.2634	.65784				
11.CONDUCTI	201.04	17.402	474	.0510	1.1101	.2675
14.NH3	.25359 -2	.16552 -2				
11.CONDUCTI	201.04	17.402	474	-.0135	-.29421	.7687
21.TOTAL P	.52287 -2	.14712 -2				
19.CHLORIDE	5.2712	.65656	480	.1081	2.3766	.0179
14.NH3	.25708 -2	.16736 -2				
19.CHLORIDE	5.2712	.65656	480	.0244	.53449	.5932
21.TOTAL P	.52256 -2	.14693 -2				
14.NH3	.25696 -2	.16720 -2	481	.3496	8.1655	.0000
21.TOTAL P	.52241 -2	.14682 -2				

indicate that a more efficient sampling program could be designed in the future based on eliminating redundant measurements.

Correlations among variables cannot be used to infer cause-and-effect relationships (Sokal and Rohlf 1969). But, the results of correlations analysis do indicate which variables covary together and if that covariance is positive or negative.

The correlations from cruise 1 reflect the well-mixed conditions typical of late winter conditions (Table 7.4). There were few large correlation coefficients, and none of these large correlations involved depth or temperature. Inverse thermal stratification was present and some vertical stratification of nutrients accompanied these conditions (see Chapter Four). But, there was little areal change in nutrient concentrations and chlorophyll. Table 7.5 shows relatively small ranges for all variables indicating uniform spatial distribution of all nutrients. The inference from these results is that spring algal growth was insufficient by cruise 1 to produce spatial patterns in nutrient levels below normal late winter maximums. Large negative correlations among Secchi depth and ammonia, total P, and chlorophyll were observed, as were negative correlations among pH, conductivity, soluble silica, and ammonia. These negative correlations suggest that some low nutrient values were found in regions of high conductivity water, e.g., the mouth of Saginaw Bay. Although outer Saginaw Bay was homothermous during cruise 1, the inner bay supported sufficient algal growth to influence nutrient concentrations of water flowing from the bay into open Lake Huron (Smith et al. 1983).

The second cruise (9-21 May) was conducted during thermal bar conditions. Spring phytoplankton blooms, common during thermal bar conditions (Davis et al. 1980) were evident from elevated chlorophyll levels between the thermal bar and

Table 7.4. Cruise 1 missing data correlations for 1980.

VARIABLE	7 DEPTH	8. TEMPERAT	9. PH	11. CONDUCTI	16. DISS OXY	17. NH3	18. NO3	19 ORTHO PO	20. SOL SIO2	21. K NITROG	26. TOTAL P	27. T FIL P
7.DEPTH	1.0000											
8.TEMPERAT	-.2723 (434)	1.0000										
9.PH	.0635 (435)	-.0672 (434)	1.0000									
11.CONDUCTI	.0993 (435)	-.2078 (434)	.6977 (435)	1.0000								
16 DISS OXY	-.2094 (149)	-.2171 (148)	.1448 (149)	.0428 (149)	1.0000							
17.NH3	-.0730 (378)	.1522 (377)	-.5340 (378)	-.6321 (378)	.0153 (125)	1.0000						
18.NO3	-.0573 (434)	-.0610 (433)	.1030 (434)	.1693 (434)	-.0052 (148)	-.0151 (378)	1.0000					
19.ORTHO PO	.2120 (380)	-.1613 (379)	-.0944 (380)	-.0708 (380)	-.0160 (125)	.3252 (378)	.0273 (380)	1.0000				
20.SOL SIO2	.0060 (433)	-.0608 (432)	-.5329 (433)	-.6139 (433)	-.1591 (147)	.5031 (377)	.0811 (433)	.2509 (379)	1.0000			
21.K NITROG	.1179 (403)	.0577 (402)	-.0478 (403)	-.1250 (403)	-.0707 (137)	.2147 (346)	-.1455 (402)	.1759 (348)	.0427 (401)	1.0000		
26 TOTAL P	-.0440 (403)	.1384 (402)	-.1072 (403)	-.0226 (403)	-.0397 (137)	.2989 (346)	.1359 (402)	.1755 (348)	.1547 (401)	.2615 (403)	1.0000	
27 T FIL P	-.0221 (399)	.0808 (398)	-.1109 (399)	-.2456 (399)	.1022 (137)	.0557 (343)	-.0197 (398)	.0169 (345)	.1802 (397)	.0224 (399)	.0428 (399)	1.0000
28.CHLOROPH	.0004 (206)	.3689 (205)	.1932 (206)	.2591 (206)	-.0975 (58)	-.0194 (170)	.3926 (206)	-.0400 (172)	-.2405 (206)	.0995 (206)	.2871 (206)	.0157 (203)
29.POC	.0230 (206)	.2940 (205)	.2897 (206)	.3533 (206)	-.0985 (58)	-.0284 (170)	.1706 (206)	-.0071 (172)	-.2595 (206)	.3450 (206)	.2557 (206)	-.0269 (203)
31.SECCHI	-0. (71)	-.3038 (71)	.3150 (71)	.2510 (71)	-.0191 (18)	-.5145 (56)	-.0224 (71)	-.2423 (57)	-.4390 (71)	-.0538 (71)	-.5097 (71)	-.3315 (70)

VARIABLE	28 CHLOROPH	29. POC	31. SECCHI
28 CHLOROPH	1.0000		
29 POC	.6920 (206)	1.0000	
31 SECCHI	-.5121 (71)	-.2575 (71)	1.0000

Table 7.5. Cruise 1 descriptive statistics for 1980.

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DESCRIPTIVE MEASURES  TABLE 4.4  -  CRUISE 1
   VARIABLE          N  MINIMUM    MAXIMUM     MEAN       STD DEV      SKEWNESS  KURTOSIS
  7.DEPTH          435  1.0000     159.00     28.285     30.751         1.450     2.074
  8.TEMPERAT       434  .70000     8.0500     2.1001     .73820         1.705     9.564
  9.PH             435  7.4400     8.4600     8.0247     .12422         -.917     4.187
 11.CONDUCTI       435  86.000     253.00     193.67     21.352        -2.448     8.473
 16.DISS OXY       149  10.600     15.400     14.029     .59563        -2.171    10.604
 17.NH3            378  0.         .46000 -1  .32354 -2  .50183 -2     5.955    41.492
 18.NO3            434  .33000 -1  .48500     .28277     .39711 -1      1.608    12.179
 19.ORTHO PO       380  .10000 -3  .90000 -2  .88526 -3  .66709 -3     6.530    63.586
 20.SOL SIO2       433  .86000     2.6400     1.4566     .27486         1.291     2.409
 21.K NITROG       403  .10700     .95000     .20110     .76751 -1      3.312    23.392
 26.TOTAL P        403  .20000 -2  .58100 -1  .57385 -2  .41385 -2     8.334    90.073
 27.T FIL P        399  .70000 -3  .28000     .35045 -2  .13926 -1    19.688   388.386
 28.CHLOROPH       206  .80000     10.000     1.7913     1.1740         5.127    32.454
 29.POC            206  .10600     .90400     .25574     .15618         2.467     6.140
 31.SECCHI          71  1.0000     12.500     7.6986     2.7303         -.172     -.779
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shore. Similar to results from 1974 (Davis et al. 1980), high nitrate-nitrogen concentrations were observed inshore of the thermal bar along with high chlorophyll concentrations (Table 7.6). Large nitrate-chlorophyll (+.524) and temperature-chlorophyll correlations (+.450) indicated this association. The cruise 2 correlation matrix (Table 7.7) yielded several other high correlations among temperature and dissolved nutrients. These correlations suggest that thermal stratification in the form of a thermal bar and its associated algal bloom had a major influence on nearshore nutrient concentrations.

Thermal bar conditions continued through the third cruise (27 May to 7 June) although the thermal bar was much further offshore than in cruise 2. The more advanced stages of the thermal bar in early June allowed some degree of vertical thermal stratification to develop inshore of the thermal bar. As a result, three distinct limnological conditions were present simultaneously in Lake Huron during cruise 3: homothermous (in the center of the lake), thermal bar (well offshore), and thermally stratified (nearshore). This mixture of limnological conditions yielded large differences in nutrient concentrations between the nearshore zone and offshore zone. Table 7.8 shows a larger range for most of the variables during cruise three than was found in cruises 1 or 2. Analysis of the entire cruise 3 data base produced relatively few high correlations (Table 7.9). Large correlations were found among temperature, depth, conductivity, POC, and Secchi depth. The high nitrate-chlorophyll association inside the thermal bar observed during cruise 2 was not present during cruise 3.

By cruise 4 (18-30 July) Lake Huron was thermally stratified in both the offshore and nearshore zones. The formation of a thermocline restricted vertical mixing and resulted in surface nutrient depletion from algal growth (Wetzel 1975). As a consequence, the major source of variation in nutrient

Table 7.6. Cruise 2 descriptive statistics for 1980.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV	SKEWNESS	KURTOSIS
7.DEPTH	503	1.0000	168.00	28.580	31.317	1.560	2.687
8.TEMPERAT	503	2.0000	11.200	4.2917	1.8285	1.001	.281
9.PH	502	7.4400	8.7200	8.0064	.13585	.296	2.764
11.CONDUCTI	503	98.000	238.00	190.56	22.144	-1.404	3.215
15.DISS OXY	163	9.4000	15.500	13.358	.66136	-1.677	9.127
16.NH3	492	.10000 -2	.35000 -1	.25407 -2	.34228 -2	6.385	47.875
17.NO3	503	.18000	.73500	.27943	.48531 -1	6.235	51.284
18.ORTHO PO	503	.10000 -3	.39000 -2	.59443 -3	.27246 -3	4.428	44.841
19.SOL SIO2	502	.77000	2.6800	1.4409	.32135	1.028	1.430
20.K NITROG	500	.68000 -1	.76200	.16763	.67978 -1	2.333	12.598
23.TOTAL P	501	.32000 -2	.16100 -1	.51756 -2	.14917 -2	2.632	10.332
24.T FIL P	494	.14000 -2	.64000 -2	.23783 -2	.61893 -3	2.432	10.444
25.CHLOROPH	256	.90000	7.8000	1.9852	1.0347	3.220	13.227
26.POC	256	.24000 -1	.72600	.21404	.12591	1.783	4.295
28.SECCHI	54	3.5000	16.000	9.2722	2.9438	.128	-.801

Table 7.7. Cruise 2 missing data correlations for 1980.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV	SKEWNESS	KURTOSIS
7.DEPTH	547	1.0000	174.00	26.864	30.299	1.740	3.503
8.TEMPERAT	545	2.7000	13.500	6.3268	2.6298	.624	-.706
9.PH	544	7.9900	8.7600	8.2599	.14691	.533	-.060
11.CONDUCTI	545	98.000	251.00	194.52	21.649	-1.133	2.285
13.DISS OXY	543	10.800	14.100	12.906	.71483	-.615	-.337
14.NH3	540	.10000 -2	.38000 -1	.27759 -2	.28251 -2	5.423	51.473
15.NO3	545	.16100	.76500	.27925	.38851 -1	4.157	49.749
16.ORTHO PO	547	.20000 -3	.21000 -2	.72486 -3	.23087 -3	1.525	6.072
17.SOL SIO2	547	.51000	2.6800	1.4240	.31889	.615	.614
18.K NITROG	545	.60000 -1	.32200	.12461	.33003 -1	1.940	7.077
21.TOTAL P	545	.28000 -2	.19900 -1	.46552 -2	.11504 -2	5.466	61.323
22.T FIL P	547	0.	.50000 -2	.20929 -2	.41818 -3	1.240	8.094
23.CHLOROPH	311	.90000	4.7000	1.8949	.58759	.854	2.260
24.POC	311	.11300	.60000	.23423	.65249 -1	1.791	6.439
26.SECCHI	73	2.5000	12.000	6.8425	2.0427	.503	.354

Table 7.8. Cruise 3 descriptive statistics for 1980.

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  VARIABLE

 7.DEPTH      1.0000

 8 TEMPERAT   -.5083    1.0000
              (503)

 9.PH         -.1073     .2178    1.0000
              (502)     (502)

11.CONDUCTI    .1156    -.2027     .6502    1.0000
              (503)     (503)     (502)

15.DISS OXY    .2861    -.5391    -.0069     .2059    1.0000
              (163)     (163)     (162)     (163)

16.NH3        -.0465     .1402    -.3268    -.4030    -.1267    1.0000
              (492)     (492)     (491)     (492)     (159)

17 NO3         .0008     .0606     .1958     .1941    -.2361     .1133    1.0000
              (503)     (503)     (502)     (503)     (163)     (492)

18 ORTHO PO   -.0052    -.0178    -.0684    -.0724     .0728     .2459     .0071    1.0000
              (503)     (503)     (502)     (503)     (163)     (492)     (503)

19 SOL SIO2    .0095    -.0813    -.5115    -.6937     .0038     .5221    -.1053     .2091    1.0000
              (502)     (502)     (501)     (502)     (162)     (492)     (502)     (502)

20.K NITROG   -.1221     .1821     .1230     .0613    -.0720     .1231     .0257    -.0160     .0213    1.0000
              (500)     (500)     (499)     (500)     (162)     (489)     (500)     (500)     (499)

23.TOTAL P    -.1636     .4707     .1257    -.1483    -.2169     .2410     .3300     .0981     .1666     .1793    1.0000
              (501)     (501)     (500)     (501)     (162)     (490)     (501)     (501)     (500)     (498)

24 T FIL P    -.1992     .3905     .0366    -.2115    -.1568     .1762     .0180     .2290     .1973     .1596     .3665    1.0000
              (494)     (494)     (493)     (494)     (161)     (483)     (494)     (494)     (493)     (491)     (492)

25 CHLOROPH    .0657     .4499     .4258     .2544    -.3001     .0193     .5244    -.0454    -.2142     .1827     .4782     .1769
              (256)     (256)     (256)     (256)     (60)      (252)     (256)     (256)     (256)     (256)     (255)     (251)

26 POC         .0835     .3848     .4602     .3433    -.1174    -.0458     .2359     .0460    -.3091     .1183     .2661    -.0064
              (256)     (256)     (256)     (256)     (60)      (252)     (256)     (256)     (256)     (256)     (255)     (251)

28 SECCHI    -0.        -.5750     .2343     .7060     .5442    -.3621     .2566    -.1437    -.7550    -.1796    -.6301    -.2828
              (54)      (54)      (54)      (54)      (8)       (53)      (54)      (54)      (54)      (54)      (54)      (52)

               7.        8.        9.        11.       15.       16.       17.       18.       19        20.       23.       24.
              DEPTH     TEMPERAT  PH        CONDUCTI  DISS OXY  NH3       NO3       ORTHO PO  SOL SIO2  K NITROG  TOTAL P   T FIL P

25 CHLOROPH   1.0000

26 POC         .6920    1.0000
              (256)

28 SECCHI     -.6906    -.3380    1.0000
              (54)      (54)

              25.       26.       28.
              CHLOROPH  POC       SECCHI
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Table 7.9. Cruise 3 missing data correlations for 1980.

VARIABLE	7. DEPTH	8. TEMPERAT	9 PH	11. CONDUCTI	13. DISS OXY	14. NH3	15. NO3	16. ORTHO PO	17 SOL SIO2	18 K NITROG	21. TOTAL P	22. T FIL P
7 DEPTH	1.0000											
8.TEMPERAT	-.6258 (545)	1.0000										
9.PH	-.2295 (544)	.2553 (544)	1.0000									
11.CONDUCTI	.1545 (545)	-.2810 (545)	.4205 (544)	1.0000								
13.DISS OXY	.5293 (543)	-.8241 (543)	-.0932 (542)	.4424 (543)	1.0000							
14.NH3	-.0209 (540)	.0657 (538)	.0190 (537)	-.1688 (538)	-.1900 (536)	1.0000						
15.NO3	.1497 (545)	-.2469 (543)	.2081 (542)	.2582 (543)	.2598 (541)	.2092 (540)	1.0000					
16.ORTHO PO	.0835 (547)	-.1852 (545)	.0532 (544)	.1756 (545)	.1802 (543)	.1646 (540)	.0887 (545)	1.0000				
17 SOL SIO2	-.0001 (547)	-.0100 (545)	-.0089 (544)	-.5139 (545)	-.1413 (543)	.4611 (540)	-.0408 (545)	.1144 (547)	1.0000			
18.K NITROG	-.0958 (545)	.2013 (543)	-.2091 (542)	-.0165 (543)	-.1871 (541)	.1276 (540)	-.1346 (545)	-.0699 (545)	-.2611 (545)	1.0000		
21.TOTAL P	.0687 (545)	.1372 (543)	.2005 (542)	.0072 (543)	-.1521 (541)	.2140 (540)	.1225 (545)	.0698 (545)	.1814 (545)	.0842 (545)	1.0000	
22.T FIL P	-.1251 (547)	.1324 (545)	.1116 (544)	.1373 (545)	-.1260 (543)	.2282 (540)	.1536 (545)	.2321 (547)	.0912 (547)	.1313 (545)	.2566 (545)	1.0000
23.CHLOROPH	.0363 (311)	.2065 (311)	.3521 (310)	.0644 (311)	-.2004 (311)	.1326 (307)	.1844 (311)	.0217 (311)	.1847 (311)	.0381 (311)	.3565 (311)	.2542 (311)
24.POC	.0647 (311)	.2876 (311)	.6271 (310)	.4400 (311)	-.1600 (311)	.1137 (307)	.4404 (311)	.0566 (311)	-.2597 (311)	.0798 (311)	.3440 (311)	.3163 (311)
26 SECCHI	-0. (73)	-.4296 (73)	-.2455 (73)	.4745 (73)	.4466 (73)	-.2285 (73)	.3104 (73)	-.0540 (73)	-.5619 (73)	-.1300 (73)	-.3668 (73)	-.1763 (73)

	23 CHLOROPH	24. POC	26. SECCHI
23.CHLOROPH	1.0000		
24 POC	.6026 (311)	1.0000	
26 SECCHI	-.6124 (73)	-.3716 (73)	1.0000

concentration shifted from areal (during thermal bar conditions) to vertical (during thermally stratified conditions). The cruise 4 correlation matrix (Table 7.10) indicates the high level of vertical change in that largest correlations were among depth, temperature, and pH. The vertical stratification also induced a larger range in most variables compared to cruises 1 to 3 (Table 7.11). This larger range primarily resulted from lower values of soluble nutrients as they were utilized by near-surface algal blooms, typical of mid-summer conditions (Moll _et al_. 1980).

Limnological conditions during cruise 5 (8-21 September) remained thermally stratified throughout Lake Huron, but a small amount of fall cooling had occurred. The fall cooling was indicated by a slightly lower mean temperature (Table 7.12). The cruise 5 correlation matrix (Table 7.13) was similar to the cruise 4 results with many high correlations among depth, temperature, and pH. Similar to cruise 4, the largest correlations among these three variables were associated with depth (because of thermal stratification) and less areal variability.

Cruise 6 (26 October to 4 November) was conducted during conditions of late thermal stratification. These conditions were represented by a rapidly cooling epilimnion. The epilimnion cooled both from atmospheric processes and a deepening thermocline which entrained hypolimnetic water. As hypolimnetic water was entrained into the expanding epilimnion, nutrient concentrations increased in the epilimnion. These rapidly changing conditions promote decoupling of the normal phytoplankton-to-nutrient relationships observed during the mid-summer. Furthermore, the thermocline was deep enough to place the majority of the water in Lake Huron into the epilimnion rather than the hypolimnion. The cruise 6 correlation matrix (Table 7.14), and descriptive statistics (Table 7.15) reflect

Table 7.10. Cruise 4 missing data correlations for 1980.

VARIABLE	7 DEPTH	8. TEMPERAT	9. PH	11 CONDUCTI	13. DISS OXY	14. NH3	15. NO3	16. ORTHO PO	17. SOL SIO2	18. K NITROG	21. TOTAL P	22. T FIL P
7 DEPTH	1.0000											
8 TEMPERAT	7362 (674)	1.0000										
9 PH	-.5637 (675)	.6184 (674)	1.0000									
11 CONDUCTI	.1677 (674)	-.1348 (673)	.3713 (674)	1.0000								
13 DISS OXY	.5005 (130)	-.6343 (130)	-.0462 (130)	.2286 (129)	1.0000							
14 NH3	.4751 (674)	-.4339 (673)	-.8417 (674)	.0313 (673)	-.0444 (129)	1.0000						
15 NO3	5348 (674)	-.5970 (673)	-.4316 (674)	.1154 (673)	.2463 (129)	.3878 (674)	1.0000					
16 ORTHO PO	.2737 (666)	-.1605 (665)	-.1388 (666)	.0510 (665)	.1881 (127)	.1349 (665)	.1652 (665)	1.0000				
17 SOL SIO2	.3808 (675)	-.4880 (674)	-.6631 (675)	-.3823 (674)	-.0908 (130)	.4337 (674)	.5116 (674)	.2160 (666)	1.0000			
18 K NITROG	.0603 (674)	-.1209 (673)	-.0410 (674)	.2238 (673)	-.1207 (129)	.3528 (674)	.1783 (674)	.0097 (665)	.0087 (674)	1.0000		
21 TOTAL P	.2217 (674)	-.3657 (673)	-.2450 (674)	-.0427 (673)	-.1411 (128)	.2988 (674)	.2366 (674)	.1573 (665)	.3406 (674)	.2429 (674)	1.0000	
22 T FIL P	.2791 (671)	-.2601 (670)	-.1504 (671)	.0553 (670)	-.0552 (129)	.3902 (671)	.2642 (671)	.3224 (662)	.2726 (671)	.1886 (671)	.4490 (671)	1.0000
23 CHLOROPH	-.0198 (435)	-.1056 (435)	-.0228 (435)	-.0589 (435)	.2371 (30)	-.0005 (435)	-.0270 (435)	.0119 (430)	.1505 (435)	-.0158 (435)	.1828 (435)	.1312 (432)
24 POC	.1007 (435)	-.1703 (435)	.3713 (435)	.3913 (435)	.3698 (30)	-.0363 (435)	.1444 (435)	.0364 (430)	-.0773 (435)	.1359 (435)	.1781 (435)	.1583 (432)
26 SECCHI	-0. (93)	-.0500 ([illegible]3)	.1067 (93)	.2896 (93)	-0.	-.3039 (93)	.1562 (93)	-.3067 (92)	-.2462 (93)	-.1131 (93)	-.6183 (93)	-.4876 (93)

VARIABLE	23 CHLOROPH	24. POC	26. SECCHI
23 CHLOROPH	1.0000		
24 POC	.2432 (435)	1.0000	
26 SECCHI	-.0484 (93)	-.0264 (93)	1.0000

Table 7.11. Cruise 4 descriptive statistics for 1980.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV	SKEWNESS	KURTOSIS
7.DEPTH	675	1.0000	170.00	23.330	28.451	2.178	5.414
8.TEMPERAT	674	3.7000	22.000	12.375	5.8114	-.006	-1.553
9.PH	675	7.0100	9.2200	8.0507	.23142	-.385	.743
11.CONDUCTI	674	101.00	264.00	190.69	19.130	-.823	3.305
13.DISS OXY	130	9.4000	13.000	11.822	.86349	-.823	-.012
14.NH3	674	.10000 -2	.21000 -1	.48947 -2	.36283 -2	1.273	1.397
15.NO3	674	.13800	.33400	.25684	.32402 -1	-.676	1.369
16.ORTHO PO	666	0.	.35000 -2	.41862 -3	.33053 -3	3.510	19.992
17.SOL SIO2	675	0.	2.5800	1.2427	.44952	.150	.496
18.K NITROG	674	.76000 -1	.29700	.16412	.34361 -1	.680	1.381
21.TOTAL P	674	.23000 -2	.19400 -1	.49583 -2	.16003 -2	2.579	16.253
22.T FIL P	671	.14000 -2	.60000 -2	.23675 -2	.48199 -3	1.861	7.828
23.CHLOROPH	435	.30000	9.4000	1.2478	.79576	7.516	73.626
24.POC	435	.11000 -1	.34100	.19857	.52773 -1	.103	.660
26.SECCHI	93	1.5000	17.600	9.0935	2.3806	.126	2.494

Table 7.12. Cruise 5 descriptive statistics for 1980.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV	SKEWNESS	KURTOSIS
7.DEPTH	602	1.0000	180.00	28.447	29.331	1.710	3.803
8.TEMPERAT	601	3.7600	22.600	11.447	5.2481	.102	-1.215
9.PH	601	7.2900	8.6600	8.1725	.18267	-.530	1.293
11.CONDUCTI	597	95.000	234.00	187.09	14.370	-1.149	5.130
13.DISS OXY	601	7.9100	14.400	10.864	1.2258	.454	-.698
14.NH3	600	.10000 -2	.17000 -1	.16667 -2	.19057 -2	4.267	20.557
15.NO3	600	.17200	.35400	.26576	.38182 -1	.276	-.592
16.ORTHO PO	600	.10000 -3	.32000 -2	.85000 -3	.35248 -3	2.015	7.862
17.SOL SIO2	600	.56000	2.5400	1.2660	.41463	.805	-.226
18.K NITROG	600	.88000 -1	.37200	.17102	.44074 -1	1.117	1.602
21.TOTAL P	600	.29000 -2	.12900 -1	.47638 -2	.12335 -2	2.099	8.797
22.T FIL P	598	0.	.48000 -2	.21657 -2	.38329 -3	1.669	10.103
23.CHLOROPH	287	.80000	2.8000	1.4355	.36006	1.207	2.123
24.POC	287	.14500	.48400	.22909	.59366 -1	1.563	3.465
26.SECCHI	68	1.5000	11.000	6.2485	2.3193	.372	-.429

Table 7.13. Cruise 5 missing data correlations for 1980.

```
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-------------------------------------------------------------------------------------------------------
  VARIABLE

7 DEPTH       1.0000

8 TEMPERAT    -.7633   1.0000
              (601)

9 PH          -.4199    .5003   1.0000
              (601)    (601)

11 CONDUCTI    .1093   -.1752    .1419   1.0000
              (597)    (597)    (597)

13 DISS OXY    .6456   -.8385   -.2353    .2887   1.0000
              (601)    (601)    (601)    (597)

14 NH3        -.0734    .0343    .0585    .1173    .1158   1.0000
              (600)    (599)    (599)    (595)    (599)

15 NO3         .7012   -.8042   -.6334    .1652    .5958   -.0100   1.0000
              (600)    (599)    (599)    (595)    (599)    (600)

16 ORTHO PO    .5302   -.3613   -.4068    .0680    .2204    .1802    .4950   1.0000
              (600)    (599)    (599)    (595)    (599)    (600)    (600)

17 SOL SIO2    .5749   -.6230   -.7162   -.1275    .2815   -.0477    .8443    .5576   1.0000
              (600)    (599)    (599)    (595)    (599)    (600)    (600)    (600)

18 K NITROG   -.1260    .1659    .1792    .0714   -.1275    .0965   -.1906   -.0788   -.1609   1.0000
              (600)    (599)    (599)    (595)    (599)    (600)    (600)    (600)    (600)

21 TOTAL P     .1677   -.2890   -.3061    .0431    .1281    .1770    .3627    .3000    .5170    .0705   1.0000
              (600)    (599)    (599)    (595)    (599)    (600)    (600)    (600)    (600)    (600)

22 T FIL P     .3153   -.2149   -.1887    .1799    .1460    .0772    .2773    .4328    .2975   -.0173    .2924   1.0000
              (598)    (597)    (597)    (593)    (597)    (598)    (598)    (598)    (598)    (598)    (598)

23 CHLOROPH    .0382    .1147    .1707    .1698   -.1101   -.0080   -.2400   -.0420    .0004    .1914    .3043    .1618
              (287)    (286)    (286)    (282)    (286)    (285)    (285)    (285)    (285)    (285)    (285)    (285)

24 POC         .0154    .2324    .2073    .2349   -.2024    .2196   -.2106    .0174   -.1078    .1937    .1964    .0666
              (287)    (286)    (286)    (282)    (286)    (285)    (285)    (285)    (285)    (285)    (285)    (285)

26 SECCHI     -0.       .2139   -.2377    .0211   -.0435    .1410    .0726    .0729   -.2947   -.1096   -.5700   -.0138
              (68)     (68)     (68)     (68)     (68)     (68)     (68)     (68)     (68)     (68)     (68)     (68)

              7        8.       9.       11.      13.      14.      15       16.      17.      18.      21.      22.
              DEPTH    TEMPERAT PH       CONDUCTI DISS OXY NH3      NO3      ORTHO PO SOL SIO2 K NITROG TOTAL P  T FIL P

23 CHLOROPH   1.0000

24 POC         .6002   1.0000
              (287)

26 SECCHI     -.3980   -.1334   1.0000
              (68)     (68)

              23       24.      26.
              CHLOROPH POC      SECCHI
-------------------------------------------------------------------------------------------------------
```

Table 7.14. Cruise 6 missing data correlations for 1980.

```
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-----------------------------------------------------------------------------------------------------------------------
 VARIABLE

7.DEPTH     1.0000

8.TEMPERAT  -.5689    1.0000
            (481)

9.PH        -.3411    .4473     1.0000
            (481)     (481)

11.CONDUCTI  .1496    .1156     .3304     1.0000
            (475)     (475)     (475)

13.DISS OXY  .3467    -.7588    -.3752    -.1443    1.0000
            (480)     (480)     (480)     (474)

14.NH3      -.1797    .6253     .3181     .0510     -.6235    1.0000
            (481)     (480)     (480)     (474)     (479)

15.NO3       .5487    -.7240    -.4227    -.1070    .4581     -.3408    1.0000
            (481)     (480)     (480)     (474)     (479)     (481)

16.ORTHO PO  .4097    -.2843    .0208     .2766     .1677     .1655     .4195     1.0000
            (481)     (480)     (480)     (474)     (479)     (481)     (481)

17.SOL SIO2  .3747    -.6541    -.3312    -.3752    .3718     -.1799    .6330     .3884     1.0000
            (481)     (480)     (480)     (474)     (479)     (481)     (481)     (481)

18.K NITROG -.1107    .3662     .1652     .1789     -.2776    .3715     -.3313    -.0706    -.3175    1.0000
            (480)     (479)     (479)     (473)     (478)     (480)     (480)     (480)     (480)

21.TOTAL P  -.1369    .1514     .2000     -.0135    -.1580    .3496     -.1755    .2659     .1205     .2322     1.0000
            (481)     (480)     (480)     (474)     (479)     (481)     (481)     (481)     (481)     (480)

22.T FIL P   .0819    .0997     .1352     .2478     -.1811    .3731     .0271     .5544     .0853     .1541     .4027     1.0000
            (474)     (473)     (473)     (467)     (472)     (474)     (474)     (474)     (474)     (473)     (474)

23.CHLOROPH  .1601    .2840     .3141     .1445     -.2135    .3480     -.5854    .1538     -.1545    .3355     .5069     .3975
            (206)     (205)     (205)     (204)     (205)     (205)     (205)     (205)     (205)     (204)     (205)     (200)

24.POC       .1594    .5376     .4620     .3822     -.4342    .5434     -.5335    .3626     -.4069    .4168     .6032     .5839
            (206)     (205)     (205)     (204)     (205)     (205)     (205)     (205)     (205)     (204)     (205)     (200)

26.SECCHI   -0.       -.0659    -.4096    .1674     .0904     -.2426    .1292     -.2442    -.1785    -.0556    -.5043    -.3110
            (69)      (69)      (69)      (69)      (69)      (69)      (69)      (69)      (69)      (69)      (69)      (67)

            7.        8.        9.        11.       13.       14.       15.       16.       17.       18.       21.       22.
            DEPTH     TEMPERAT  PH        CONDUCTI  DISS OXY  NH3       NO3       ORTHO PO  SOL SIO2  K NITROG  TOTAL P   T FIL P

23.CHLOROPH 1.0000

24.POC       .7711    1.0000
            (206)

26.SECCHI   -.4744    -.3898    1.0000
            (69)      (69)

            23        24.       26.
            CHLOROPH  POC       SECCHI
-----------------------------------------------------------------------------------------------------------------------
```

Table 7.15. Cruise 6 descriptive statistics for 1980.

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV	SKEWNESS	KURTOSIS
7.DEPTH	482	1.0000	172.00	33.756	32.572	1.049	.955
8.TEMPERAT	481	3.8300	11.600	7.5464	1.7158	.008	-.405
9.PH	481	7.1500	8.5600	8.1320	.17311	-1.230	5.920
11.CONDUCTI	475	99.000	267.00	201.08	17.401	-.976	6.655
13.DISS OXY	480	9.6300	13.900	11.637	.55886	.378	.798
14.NH3	481	.10000 -2	.10000 -1	.25696 -2	.16720 -2	1.196	1.206
15.NO3	481	.16300	.34300	.27596	.31124 -1	-.419	.901
16.ORTHO PO	481	.20000 -3	.31000 -2	.63056 -3	.37294 -3	2.682	10.286
17.SOL SIO2	481	.75000	2.2100	1.3882	.30606	.506	-.745
18.K NITROG	480	.84000 -1	.50400	.16868	.47190 -1	1.680	6.823
21.TOTAL P	481	.31000 -2	.15700 -1	.52241 -2	.14682 -2	2.693	11.985
22.T FIL P	474	.14000 -2	.68000 -2	.23776 -2	.61696 -3	2.342	9.647
23.CHLOROPH	206	.60000	4.7000	1.6447	.73015	2.017	5.045
24.POC	206	.11400	.59600	.22901	.96689 -1	1.585	2.333
26.SECCHI	69	1.0000	9.0000	4.2754	1.8875	.586	.055

the increase in dissolved materials in the epilimnion. Mass of nutrients was conserved throughout the lake and simply mixed from the hypolimnion upward into the epilimnion. But, the sampling program was somewhat biased toward sampling in the epilimnion, i.e., more samples were taken in the epilimnion than hypolimnion. As a result, the descriptive statistics (Table 7.15) show a uniform increase in dissolved nutrient concentration from cruise 5 to cruise 6.

The results from the southern Lake Huron 1974 study (Moll 1980) showed an annual seasonal cycle of soluble silica depletion. This cycle, originally defined by Schelske and Stoermer (1971), was evident in the 1974 results by a large negative correlation between soluble silica and chlorophyll from late June through October. The 1980 results presented here do not yield these high negative correlations. Rather, the correlations among most soluble nutrients and chlorophyll were generally small (statistically non-significant from 0.00) and negative. These results should not be taken to imply a change in nutrient-phytoplankton relationships, but rather more as a consequence of the experimental design. The large area of the Lake Huron survey includes several different water types (see Chapters Five and Six), each with a somewhat different nutrient regime. These nutrient regimes promote different phytoplankton assemblages (Stoermer 1978) which have different nutrient requirements. Under these conditions, the lake-wide correlation matrix has limited inferences other than general trends such as an increase in variability with depth after the onset of thermal stratification.

Factor Analyses

Factor analyses carry the correlation analyses further in that a few underlying sources of covariance are sought among the variables sampled (Kim and Mueller 1978). These sources of variation are exposed in several ways. One method is the calculation of communalities or the proportion of variation in one variable which is shared by all other variables included in the analysis. Additionally, factor analysis reduces the number of variables in a data set by composing factors or linear combinations of the original variables (Harman 1967). The order in which the analysis extracts the individual factors indicates where the highest source of covariance lies. Thus, the first factor contains more covariance than the second which explains more than the third factor and so on.

The cruise 1 factor analysis yielded five factors (Table 7.16). The first and major factor had high loadings[1] for soluble silica, ammonia, pH, and conductivity (last two opposite in sign from first two). This factor was taken to represent the high silica-low conductivity water mass covering much of northern Lake Huron. The remaining four factors each had high loadings for only one or two variables. Temperature had high loadings on the fifth and least important factor. These results were indicative of the well-mixed, early spring conditions typical of homothermous water masses. Strong inter-variable relationships were lacking throughout Lake Huron in April 1980. This hypothesis was supported by the low communalities of the cruise 1 factor solution.

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[1] The reader is cautioned about the confusing use of the term loadings in this section. In a limnological context, loading is often used to indicate a high nutrient input or nutrient loading. In a statistical context, factor loading refers to the coefficient in a factor pattern matrix. Throughout the remainder of this chapter, the term loading(s) indicates a statistical score. High inputs of nutrients are referred to as nutrient loading(s).

Table 7.16. Cruise 1 factor solution results for 1980.

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---------------------------------------------------------------------------
ITERATION     (1)        (2)        (3)        (4)        (5)
CRITERION   2.5590     5.2860     5.3737     5.3747     5.3747

PAIRWISE VARIMAX ON 5 FACTORS WITH NORMALIZED LOADINGS

    VARIABLE     COMMUNALITY   (1)          (2)          (3)          (4)          (5)

  8.TEMPERAT      .61233     .10526      -.38458 -1 -.76882       .40411 -1 -.84009 -1
  9.PH            .58006    -.75795       .18946 -1  .96476 -2 -.32890 -1  .63548 -1
 11.CONDUCTI      .88266    -.88925       .13453     .21348    -.15046 -1  .16732
 17.NH3           .69194     .72042       .44757 -1 -.77792 -1  .40420      .38678 -1
 18.NO3           .59176    -.44678 -1    .61307 -2  .94816 -1 -.10174 -1  .76199
 19.ORTHO PO      .24915     .19765       .56798 -2  .26645      .37171      .29871 -1
 20.SOL SIO2      .61899     .74314      -.10408     .12012      .15455      .13262
 21.K NITROG      .32277     .26643 -1 -.82237 -2 -.18652 -1  .53288     -.19412
 26.TOTAL P       .37230     .11842      -.24950 -1 -.96572 -1  .53329      .25283
 27.T FIL P       .97868     .11980      -.98072    -.46008 -1  .19585 -1 -.51474 -2

                SUM SQRS   2.5177       .99534      .74901      .89723      .74134
                % VARIANCE   25.2         35.1        42.6        51.6        59.0

SCALED FACTOR SCORES

    VARIABLE          (1)          (2)          (3)          (4)          (5)

    CONSTANT       O.           O.           O.           O.           O.
  8.TEMPERAT     -.80742 -1   .22222 -1 -.69293       .45096 -1   .62122 -1
  9.PH           -.16411     -.17385 -1 -.64148 -1   .82601 -1 -.17289 -1
 11.CONDUCTI     -.62410     -.73799 -1  .22803       .35464      .24580
 17.NH3           .14493      .35710 -1  .23007 -1   .41758      .86948 -1
 18.NO3           .35291 -1 -.79298 -3 -.40290 -1 -.74608 -1   .68600
 19.ORTHO PO      .29234 -1   .56560 -2  .12246       .15054     -.30370 -1
 20.SOL SIO2      .17883      .13757 -2  .19679       .63177 -1   .17154
 21.K NITROG     -.89548 -1 -.10507 -1  .10377 -1   .36110     -.11537
 26.TOTAL P       .24384 -2   .10492 -1 -.96606 -1   .31082      .11148
 27.T FIL P      -.86219 -1 -1.0057      .28720 -1   .50667 -1   .23361 -1
---------------------------------------------------------------------------
```

The cruise 2 factor analysis produced five factors (Table 7.17) and relatively large communalities. The first and most important factor had high loadings for pH, conductivity, ammonia, and soluble silica, with the last two opposite in sign to the first two variables. This was the same result as from the cruise 1 factor analysis. Again, this factor was interpreted as representing the high silica-low conductivity water covering most of the open northern Lake Huron. The second factor had high loadings for temperature, total phosphorus, and total filtered phosphorus. With the onset of thermal bar conditions during cruise 2, temperature became a more important influence than it was during cruise 1; the temperature communality increased between cruise 1 and 2. The remaining three factors had high loadings for only one variable, implying that no single underlying mechanism was controlling the soluble nutrients together.

The cruise 3 factor solution yielded four factors and a large range in the value of the communalities (Table 7.18). With the development of the thermal bar well offshore, thermal stratification inshore of the bar accounted for a large portion of Lake Huron water. The temperature communality was large, while the communalities associated with the various forms of phosphorus (total, total filtered, and soluble) were small. The first factor had high loadings for phosphorus (total and total filtered) and ammonia. Highest total phosphorus levels were found offshore of the thermal bar and in the vicinity of river mouths. This factor implied that several regions of uniformly high nutrients were found throughout Lake Huron, particularly offshore of the thermal bar. The second factor had high loadings for conductivity and soluble silica (opposite in sign). Most of northern Lake Huron remained covered by high silica-low conductivity water, while the mouth of Saginaw Bay had low silica-high conductivity water.

Table 7.17. Cruise 2 factor solution results for 1980.

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ITERATION     (1)        (2)        (3)        (4)        (5)
CRITERION   2.5356     5.3471     5.5291     5.5294     5.5294

PAIRWISE VARIMAX ON 5 FACTORS WITH NORMALIZED LOADINGS

    VARIABLE     COMMUNALITY   (1)          (2)          (3)          (4)          (5)

  8.TEMPERAT       .71301    -.59638 -1   .83645       .57961 -1  -.79038 -1  -.14275 -1
  9.PH             .59726    -.72793      .20715       .84141 -1   .78095 -2   .13162
 11.CONDUCTI       .87360    -.87272     -.26381       .87408 -1   .68017 -1   .17349
 16.NH3            .41238     .53333      .17012       .11892      .21032      .20157
 17.NO3            .63573    -.90311 -1   .61992 -1  -.16370 -3  -.47309 -2   .78975
 18.ORTHO PO       .72665     .10852      .81568 -1  -.21241 -1   .84129      .26069 -2
 19.SOL SIO2       .68114     .80694      .52314 -1   .43516 -1   .15837      .16831 -1
 20.K NITROG       .89583    -.23064 -1   .15886       .93254     -.14726 -1   .14308 -1
 23.TOTAL P        .53608     .99117 -1   .60515       .82266 -1   .56008 -1   .38749
 24.T FIL P        .33169     .13281      .51044       .96315 -1   .21018     -.71451 -2

                 SUM SQRS    2.2786      1.5063       .92025      .83556      .86265
                 % VARIANCE   22.8        37.8         47.1        55.4        64.0

SCALED FACTOR SCORES

    VARIABLE        (1)          (2)          (3)          (4)          (5)

    CONSTANT      0.           0.           0.           0.           0.
  8.TEMPERAT    -.16498       .59319      -.73841 -1  -.40489 -1  -.81673 -1
  9.PH          -.15256       .16460      -.28342 -1  -.49139 -2  -.24778 -1
 11.CONDUCTI    -.60028      -.19723       .99999 -1   .26692      .22068
 16.NH3          .13480      -.68103 -2    .19163 -1   .44018 -1   .11173
 17.NO3          .45351 -1  -.40334 -1   -.22508 -1  -.44764 -1   .69083
 18.ORTHO PO    -.27143 -1   .29140 -1   -.13523 -1   .80756     -.53630 -1
 19.SOL SIO2     .23091      -.31815 -1    .77647 -1   .14120      .14214
 20.K NITROG     .34359 -1  -.26275 -1    .94909     -.23841 -1  -.45523 -1
 23.TOTAL P      .20954 -1   .23549      -.29124 -1   .15620 -2   .20950
 24.T FIL P     -.88143 -2   .14783      -.13057 -1   .66687 -1  -.34601 -1
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Table 7.18. Cruise 3 factor solution results for 1980.

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ITERATION    (1)       (2)       (3)       (4)       (5)       (6)       (7)       (8)       (9)       (10)      (11)
CRITERION  2.4001    3.2372    3.6069    3.6397    3.6511    3.6594    3.6656    3.6703    3.6740    3.6768    3.6788

  (12)      (13)      (14)      (15)      (16)      (17)      (18)      (19)      (20)
 3.6803    3.6812    3.6819    3.6823    3.6825    3.6826    3.6827    3.6827    3.6827

PAIRWISE VARIMAX ON 4 FACTORS WITH NORMALIZED LOADINGS

     VARIABLE      COMMUNALITY   (1)         (2)           (3)           (4)

  8.TEMPERAT       .84954     .21870     -.22095 -1  -.88724        .11841
  9.PH             .70453     .26736      .18684     -.11925        .76414
 11.CONDUCTI       .82441     .14727      .72646      .39655        .34311
 14.NH3            .43983     .55307     -.34837      .80508 -1  -.78170 -1
 15.NO3            .22788     .25098      .88944 -1   .33121        .21741
 16.ORTHO PO       .15675     .26876     -.20031 -1   .28654        .44847 -1
 17.SOL SIO2       .85419     .24458     -.88144      .84268 -1    .10159
 18.K NITROG       .50542     .30124      .28995     -.25824       -.51372
 21.TOTAL P        .19388     .41968     -.58329 -1  -.59224 -1    .10413
 22.T FIL P        .31807     .55911      .61410 -1   .29983 -1    .28181 -1

                   SUM SQRS   1.2214      1.5610       1.2352       1.0569
                   % VARIANCE   12.2        27.8         40.2         50.7

SCALED FACTOR SCORES

     VARIABLE          (1)          (2)          (3)          (4)

     CONSTANT        0.           0.           0.           0.
  8.TEMPERAT        .23291       .41673 -1  -.77585       .15259
  9.PH              .33888 -1    .29539 -1  -.59636 -1    .55474
 11.CONDUCTI        .31723       .38613       .22935       .24978
 14.NH3             .27799     -.42779 -2    .95769 -1  -.10485
 15.NO3             .13548     -.32446 -1    .50974 -1    .57553 -1
 16.ORTHO PO        .10796     -.65092 -2    .48193 -1  -.16298 -1
 17.SOL SIO2        .30296     -.65507       .11744       .21256
 18.K NITROG        .28303      .10862     -.92101 -1  -.34170
 21.TOTAL P         .15657      .18277 -1  -.58472 -3  -.41911 -2
 22.T FIL P         .24875      .43033 -1    .64962 -1  -.61298 -1

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The factor analysis for cruise 4 produced only three factors. The first and clearly dominant factor was interpreted as representing variability due to depth (Table 7.19). This factor had high loadings for NH_3, NO_3, soluble silica, pH, and temperature, with the last two variables opposite in sign to the first three. These five variables were observed to change rapidly with depth during periods of thermal stratification. The second factor had high loadings for conductivity alone. This factor was taken to represent high conductivity water from Saginaw Bay mixing into open Lake Huron. During periods of thermal stratification, Saginaw Bay water has been observed to flow far out into southern Lake Huron along the surface (Moll et al. 1980). The third factor had high loadings for total phosphorus and total filtered phosphorus. This factor was interpreted as representing high phosphorus water in most of the nearshore zones of Lake Huron.

The cruise 5 factor solution (Table 7.20) produced five factors. Similar to the cruise 4 results, the first factor represented variability associated with increasing depth. This factor had high loadings for temperature, pH, NO_3, and soluble silica, with the first two opposite in sign to the last two. The fourth factor in the cruise 5 solution was similar to the second factor from cruise 4, with high loadings for conductivity. The interpretation of this factor was the same as before, representing high conductivity in Saginaw Bay water. Factors two, three, and five had high loadings for ammonia, Kjeldahl nitrogen, and total filtered phosphorus, respectively. These three factors were taken to represent different types of nearshore water enriched in a particular nutrient.

Table 7.19. Cruise 4 factor solution results for 1980.

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ITERATION     (1)        (2)        (3)        (4)
CRITERION   1.7777     3.4387     3.4475     3.4475

PAIRWISE VARIMAX ON 3 FACTORS WITH NORMALIZED LOADINGS

     VARIABLE     COMMUNALITY   (1)          (2)          (3)

   8.TEMPERAT      .67289     -.77217      -.18112      -.20938
   9.PH            .77898     -.81461       .31842      -.11833
  11.CONDUCTI      .89774     -.78733 -1    .84387       .21455 -1
  14.NH3           .44144      .52208       .61331 -1    .40634
  15.NO3           .48060      .63731       .15725       .22297
  16.ORTHO PO      .11014      .12480       .68492 -2    .30744
  17.SOL SIO2      .67302      .68408      -.34913       .28839
  18.K NITROG      .14899      .11772       .24793       .27141
  21.TOTAL P       .32873      .25646      -.13087 -1    .51263
  22.T FIL P       .71702      .85681 -1    .41088 -1    .84142

                  SUM SQRS    2.5153       1.2390       1.4953
                  % VARIANCE   25.2         37.5         52.5

SCALED FACTOR SCORES

     VARIABLE         (1)          (2)          (3)

     CONSTANT       0.           0.           0.
   8.TEMPERAT      -.27943      -.61914 -1    .32832 -1
   9.PH            -.47965       .13881 -1    .13674
  11.CONDUCTI       .14070       .89915      -.41227 -1
  14.NH3            .35609 -1    .20802 -1    .10223
  15.NO3            .15734       .57195 -1   -.25943 -1
  16.ORTHO PO      -.18254 -1   -.36448 -1    .48863 -1
  17.SOL SIO2       .23325      -.60427 -1    .90985 -1
  18.K NITROG       .21834 -1    .30530 -1    .83044 -1
  21.TOTAL P       -.69231 -2    .24060 -1    .15065
  22.T FIL P       -.17892      -.31362 -1    .71463

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Table 7.20. Cruise 5 factor solution results for 1980.

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ITERATION    (1)        (2)        (3)        (4)        (5)        (6)
CRITERION   2.4422     4.7774     4.8423     4.8445     4.8445     4.8445

PAIRWISE VARIMAX ON 5 FACTORS WITH NORMALIZED LOADINGS

    VARIABLE     COMMUNALITY   (1)          (2)          (3)          (4)          (5)

  8.TEMPERAT      .64545     -.74978       .48681 -1   .10644      -.25977      -.45902 -1
  9.PH            .55084     -.69634       .36564 -1   .98201 -1    .19630      -.12817
 11.CONDUCTI      .54291      .30639 -2    .60562 -1   .43723 -1    .72545       .10507
 14.NH3           .95369     -.13792 -1    .96994      .46691 -1    .76840 -1    .68031 -1
 15.NO3           .96592      .94386      -.17344 -1 -.10653        .23437       .92054 -1
 16.ORTHO PO      .43739      .48056       .16663     -.39845 -1    .39312 -2    .42082
 17.SOL SIO2      .97715      .92848      -.14134 -1 -.22471 -1  -.23021        .24775
 18.K NITROG      .81239     -.11624       .43350 -1   .89134       .50006 -1  -.28921 -2
 21.TOTAL P       .29909      .41497       .16524      .14406      -.38285 -1    .27814
 22.T FIL P       .73368      .16611       .93678 -2 -.93118 -2     .14932       .82681

                 SUM SQRS    3.2444       1.0057       .85384       .77241      1.0421
                 % VARIANCE   32.4          42.5         51.0         58.8         69.2

SCALED FACTOR SCORES

    VARIABLE         (1)          (2)          (3)          (4)          (5)

    CONSTANT        O.           O.           O.           O.           O.
  8.TEMPERAT      -.44222 -1  -.15017 -1  -.20406 -1    .33577 -1  -.14343 -1
  9.PH            -.33145 -1   .29097 -2   .32630 -1    .75016 -1   .18463 -1
 11.CONDUCTI      -.61847 -2   .12663 -1   .52824 -1    .30768      .12092
 14.NH3            .26529 -1   .99632     -.20264 -1  -.73198 -1    .10746 -2
 15.NO3            .53625     -.16457     -.18672      1.3080      -.62455
 16.ORTHO PO      -.31923 -1  -.23084 -1  -.37410 -1    .79250 -1   .10086
 17.SOL SIO2       .50106      .20510      .31612     -1.3810       .50831
 18.K NITROG       .68336 -1  -.44326 -1   .89684       .43405 -1  -.25626 -1
 21.TOTAL P       -.18930 -1  -.35894 -1   .37375 -2    .17513     -.22958 -1
 22.T FIL P       -.13116     -.65607 -1  -.26046 -1    .88382 -1   .78831

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The cruise 6 factor solution was similar to the cruise five results. Five factors were extracted (Table 7.21), with the first factor representing the variability associated with depth. Factor three is the high conductivity factor, while factors two, four, and five have high loadings for orthophosphorus-total filtered phosphorus, Kjeldahl nitrogen, and total phosphorus respectively. These three factors were again considered to represent nearshore waters which had high nutrient loadings.

Discussion

The statistical analyses presented above yielded three major ecological inferences about Lake Huron. First, it is an oligotrophic ecosystem with low concentrations of nutrients and small annual ranges in nutrient concentrations. Second, physical processes have a major effect on the distribution of water masses in Lake Huron, while biological processes affect the concentration of nutrients within water masses. Third, a major transition in limnological conditions occurs when the lake changes from thermal bar conditions to thermally stratified conditions.

The first inference, that Lake Huron is an oligotrophic ecosystem, comes from the means, ranges, and variances. Small ranges and coefficients of variation imply small extremes in nutrient conditions throughout the lake. Furthermore, small ranges suggest an absence of high nutrient loadings which stimulate large algal crops. The ranges for the major nutrients in Lake Huron during 1980 are small when compared to more eutrophic lakes, i.e., Lake Erie (Burns 1976). The mean value of the nutrient concentrations throughout Lake Huron also exemplifies oligotrophic conditions when compared to other lakes. However,

Table 7.21. Cruise 6 factor solution results for 1980.

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ITERATION     (1)       (2)       (3)       (4)       (5)       (6)       (7)       (8)       (9)       (10)
CRITERION   2.9404    3.8604    3.9625    3.9772    3.9820    3.9837    3.9842    3.9843    3.9844    3.9844

PAIRWISE VARIMAX ON 5 FACTORS WITH NORMALIZED LOADINGS

   VARIABLE     COMMUNALITY   (1)        (2)          (3)          (4)          (5)

   8.TEMPERAT     .96494    .96345     -.44242 -1   .42142 -1   .18132       .93885 -2
   9.PH           .36951    .45730      .56828 -1   .33621      .57293 -3   .21006
  11.CONDUCTI     .76189    .79055 -1   .23394      .82996      .90484 -1  -.62374 -1
  14.NH3          .67006    .66530      .42248     -.10762      .14884       .12338
  15.NO3          .73103   -.70837      .33431     -.18092     -.15868      -.24406
  16.ORTHO PO     .80936   -.26335      .83531      .15721     -.74725 -1   .10939
  17.SOL SIO2     .71032   -.58553      .32590     -.44609     -.20450       .14299
  18.K NITROG     .76868    .21568      .34550 -1   .10286      .83400       .12181
  21.TOTAL P      .66411    .14412      .32172     -.70549 -1   .13723       .71835
  22.T FIL P      .49500    .11691      .63469      .11535      .95845 -1   .23666

                 SUM SQRS   2.5812     1.6616      1.1005       .85937       .74217
                 % VARIANCE   25.8       42.4        53.4        62.0         69.4

SCALED FACTOR SCORES

   VARIABLE        (1)         (2)         (3)         (4)         (5)

   CONSTANT      O.          O.          O.          O.          O.
   8.TEMPERAT     .93437      .25929     -.25390     -.12287     -.37873
   9.PH           .58275 -2 -.40300 -1   .10860     -.73263 -1   .12724
  11.CONDUCTI    -.13887 -1  .76768 -1   .68945     -.35288 -1 -.56629 -1
  14.NH3          .80137 -1  .22673     -.14987      .18296 -1 -.33347 -1
  15.NO3         -.92715 -1  .23440     -.17331      .80624 -1 -.39231
  16.ORTHO PO     .36308 -1  .61543      .94428 -1 -.72949 -1 -.77923 -1
  17.SOL SIO2     .29677 -1  .16092     -.28771     -.65539 -1   .89841 -1
  18.K NITROG    -.15670      .55748 -2 -.40442 -1   .89198     -.16772 -1
  21.TOTAL P     -.24742 -1 -.16979 -2 -.10009 -1 -.13490 -1   .68851
  22.T FIL P     -.13260 -2  .14950     -.11643 -2  .29073 -1   .54366 -1

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comparison of means among different ecosystems almost always implies comparison of means among different studies and/or analytical laboratories. Because analytical procedures vary among laboratories, results are rarely comparable without some biases. The comparison of scale-free ranges (coefficients of variation or relvariances) provides inferences among different lakes without bias. These statistics from Lake Huron underscore the oligotrophic characteristic of the ecosystem when compared to Lakes Michigan and Erie (Rockwell et al. 1980, Burns 1976).

The second inference, that nutrient distributions in Lake Huron were primarily controlled by physical events, was developed by considering the results of the correlation and factor analyses. These results show major associations among the conservative variables and many of the non-conservative nutrients. For example, temperature-nutrient correlations were large and negative for cruises 4 to 6. These correlations, which are commonly observed in many lakes, are the consequence of nutrient depletion by near-surface phytoplankton. Although the algae are responsible for the nutrient reduction, the physical process of thermal stratification separates the epilimnion from the hypolimnion. Thus, physical processes were responsible for the distribution of water masses while biological processes controlled the concentration of nutrients within each water mass.

Other examples of this general mechanism were made more visible with the aid of the multivariate analyses. The factor analyses showed that the major water masses of Lake Huron had distinct characteristics which often persisted across several months. Although the concentration of many nutrients changed within these water masses during the biologically important months, the relationships among the variables remained relatively constant so that the same water masses from several different cruises were identified by factor analyses.

This third inference, that Lake Huron underwent a major limnological change during the transition from thermal bar to thermally stratified conditions, was also derived from the factor analysis. The six factor analyses considered together show a clear change in limnological conditions between cruises 1 to 3 and 4 to 6. The first three cruises were conducted during homothermous and thermal bar conditions. These are periods of intense spatial and vertical mixing (Scavia and Bennett 1980). As a result, the factor analyses identified only one or two major factors that had straightforward ecological interpretation. Major factors in Lake Huron during cruises 1 to 3 were primarily due to large geographic differences in water quality. The major factor observed was the high silica-low conductivity of northern Lake Huron.

The factor solutions from cruises 4 to 6 showed the large influence of thermal stratification. Surface temperatures varied considerably among these three cruises. However, the first and by far most dominant factor in each of the three analyses was variation with depth. The results indicate that once thermal stratification becomes established, a series of events takes place to alter the vertical distribution of many variables. The transition from homothermous to stratified conditions occurred rapidly in Lake Huron between early June and mid-July.

CHAPTER EIGHT

LONG-TERM TRENDS IN NUTRIENT CONCENTRATIONS IN LAKE HURON

by Russell Moll, Ronald Rossmann, and William Y. B. Chang

A major objective of the Great Lakes Intensive Surveillance Program is to identify long-term trends in the water quality of each of the Great Lakes. These long-term trends are one of the few mechanisms used to judge the overall impact man has made on the Great Lakes. Lake-wide measurements made within one year or across two or three adjacent years rarely indicate an overall trend in water quality. Only through analysis of data collected over an extended period (such as a decade or more) can more reliable general trends in water quality, fish stocks, etc. be identified.

Most of the long-term changes observed in the Great Lakes have been a consequence of accelerated rates of eutrophication from anthropogenic nutrient loadings (Beeton 1969). The consequences of the increase in eutrophication have been shifts in species composition and abundance (Stoermer and Yang 1970, Davis 1964, Christie 1974). Although the results of long-term species shifts are evident from the flora and fauna, the primary mechanism responsible for those shifts is changes in the dissolved nutrient pools (Schelske and Stoermer 1971). Because of this, the surveillance of long-term changes in the nutrient concentrations is of primary importance in the Great Lakes.

The 1980 study of Lake Huron presents an opportunity to extend the historical database by another six years; the previous lake-wide study of Lake Huron was completed in 1974 (IJC 1976). Lake Huron, along with Lake Superior, is considered one of the most oligotrophic of the Great Lakes (IJC 1976). Nutrient loadings to the Lake Huron ecosystem are primarily confined to the southern basin, and more specifically to Saginaw Bay and the extreme southern Ontario shore (Schelske _et_ _al_. 1980, Bierman and Dolan 1981). Over the past five years, nutrient loads in these regions decreased considerably due to mitigating actions taken by local municipalities (Bierman _et_ _al_. 1982). As a result, long-term trends have changed over the past decade. The results presented below show curvilinear long-term trends for several variables over the last 30 years.

The term "long-term trend" can include a variety of different processes depending on the specific trend of interest. This chapter deals with three types of long-term trends in Lake Huron: 1) changes in mean nutrient concentrations across a period of 10 years or more holding the effect of season constant, 2) changes in the range of variables among years, and 3) changes in the areal extent of homogeneous water masses among years. The first type of trend is used most commonly to evaluate the overall status of a Great Lakes ecosystem.
A simple comparison of means across years reveals whether or not nutrient concentrations have changed, which in turn may cause species shifts. Extreme care must be taken to make this comparison for the same season of each year. Seasonal effects can have a major influence on mean nutrient concentrations and thus either mask significant long-term trends or give the false impression that a trend exists (Richards 1981a). The second type of long-term trend is used to evaluate the magnitude of seasonal fluctuations of non-conservative variables. A large annual range of dissolved nutrients indicates high nutrient loadings stimulating large algal crops (Vollenweider _et_ _al_. 1974). A large annual range can also be the result of a high degree of spatial heterogenity (see Chapter Five). The third type of annual trend follows from above in that the areal extent of high-nutrient or low-nutrient water masses can be compared across years. This type of comparison is used to assess the extent that point-source

nutrient inputs affect the lake. This chapter deals primarily with the first two types of long-term trends in Lake Huron: 1) comparison of means across years and 2) changes in annual ranges.

Historical Database

The modern historical database for Lake Huron begins in 1954 (Ayers *et al.* 1956) and proceeds through 1980 (see Chapter Three). The historical database includes studies in the following years: 1954 (Ayers *et al.* 1956); 1956 (Allen 1964); 1966, 1967 (Kramer 1968); 1968, 1969 (CCIW 1968, 1969); 1970 (Schelske and Roth 1973); 1971, 1972, and 1973 (CCIW STAR data); and 1974 (Schelske *et al.* 1980). Most of these studies were conducted in the mid-summer through late fall (Table 8.1); but the 1971, 1972, 1973, and 1974 studies also included spring cruises. Because the nutrient dynamics and biological characteristics of this lake are considerably different in spring and summer, comparisons of means across years for the purpose of identifying long-term trends are made for each season (Table 8.1). Summer is not a good season for annual long-term trend analysis, because during this period thermal stratification is already well developed (Boyce 1974). As a result of this, surface nutrients are depleted by algae (Moll *et al.* 1980), and vertical nutrient profiles are markedly different. The experimental design of a research cruise conducted during the summer can very much affect the mean and range of many variables.

The types of variables measured over the past 30 years have changed along with analytical methodology. Table 8.2 shows that relatively few dissolved nutrient analyses were conducted in the late 1950s (mostly silicon). By 1968, a fairly complete suite of analyses were conducted as a routine basis on most

Table 8.1. Lake Huron historical database: sampling frequency.

Month	1954	1956	1966	1967	1968	1969	1970	1971	1972	1973	1974	1980
April								X			X	X
May								X	X	X	X	X
June	X	X	X	X				X			X	X
July	X	X	X	X			X	X			X	X
August	X	X	X	X	X			X	X		X	
September		X				X				X	X	X
October								X			X	X
November						X		X	X		X	X
December						X		X				

Table 8.2. Lake Huron historical database: nutrient and other analyses.

Variable	1954	1956	1966	1967	1968	1969	1970	1971	1972	1973	1974	1980
Ammonia						X	X				X	X
Chloride	X			X	X	X	X	X	X	X	X	X
Chlorophyll											X	X
Conductivity	X	X	X	X	X	X	X	X	X	X	X	X
Nitrate					X	X	X	X	X	X	X	X
Secchi							X	X	X	X	X	X
Silicon	X	X	X	X	X	X	X	X	X	X	X	X
Sol. Phosphate			X	X	X	X	X	X	X	X	X	X
Sulfate		X	X	X	X	X	X	X			X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X
Total P					X	X	X	X	X	X	X	X

research cruises. Analytical methodology changed considerably across the 30 years of study. However, corrections for bias cannot easily be made across years. The long-term trends developed in this chapter have not adjusted the data for inter-lab or inter-year differences.

Statistical Methods

A variety of methods have been used to evaluate long-term trends in the Great Lakes. These methods frequently include graphical techniques, deterministic models, and statistical models. The techniques presented below are primarily statistical models. The major reasons behind the use of statistical models is that they take into account the stochastic nature of the ecosystem and provide probability statements to attach to inferences concerning long-term trends.

The statistical procedures used to determine long-term trends were part of the University of Michigan statistical package MIDAS. This is a large, interactive data management and analysis package which provides software for univariate and multivariate analyses (Fox and Guire 1976). The protocol in analyzing the long-term trends was as follows: A database with 12 years of data was created. Data were available from 1954, 1956, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, and 1980. Eight analytical variables were included in this database: temperature, conductivity, chloride, sulfate, soluble silica, nitrate-nitrogen, dissolved reactive phosphate, and total phosphorus.

Each variable was analyzed to determine whether or not it was normally distributed within each year. This was accomplished by examining the skewness and kurtosis of each variable and comparing the mean to the median. Most of the variables had relatively low skew, generally below 2.0. However, some parameters in the data showed deviation from normality, especially soluble phosphate. In those cases, comparisons between medians and means were made. A large difference between medians and means suggests a lack of normality and is evidence for the need to use non-parametric analysis. The results showed little difference between the means and medians. Although in a few cases the data were not normally distributed, the conclusion from this analysis was that the data were close enough to being normally distributed for the use of parametric analyses.

Analyses for long-term trends in Lake Huron were conducted as a two-step statistical procedure. The first hypothesis tested was to determine if the variable(s) changed among years. This hypothesis was tested using ANOVA with the null hypothesis that there is no difference among years versus the alternative hypothesis that at least two different years are statistically different. The statistical procedure used was a one-way ANOVA with unequal cell sizes (Winer 1971).

After confirming that there were significant differences across years, the analysis proceeded to determine if a linear or curvilinear trend was present across years. The null hypothesis tested for each variable was that there was no linear trend across years (slope is 0.0) versus the alternative that there was a significant slope (Netter and Wasserman 1974). The linear and curvilinear trends were analyzed by a least squares stepwise polynomial procedure. In this technique, a linear model was fit to the data followed by a quadratic model. An F-test was conducted to determine if the quadratic fit significantly improved the linear fit. The final results of the ANOVA and regression analyses were combined into one ANOVA table with a linear decomposition of the treatment sums of squares for the regression model (Netter and Wasserman 1974). In some cases, however, polynomial fitting was extended beyond the quadratic term if a significant gain in R^2 resulted from the inclusion of higher order terms, and nonzero-regression coefficients were obtained for these terms after such an inclusion. The best polynomial equation for describing a data set was then chosen to represent the curvilinear trend of the data. The results from these polynomial fits are presented along with linear fits in the figures which follow. For the data considered, the significance of nonlinearity as indicated by quadratic terms is not different from that shown by the inclusion of the higher order terms. The authors recognize that significant higher order polynomial fits to the data are not useful for predicting trends but are useful for describing changes within parameters over a designated period of time. Such curves are useful for describing long-term variations of parameters. Superimposed on these variations may be a long-term linear trend.

Long-term trends were also analyzed by comparing homogeneous water masses across years. Using the same analytical techniques as in Chapter Six, homogeneous water masses were identified from surface samples of one research cruise for each year. The statistical procedures used were cluster analysis and discriminant functions analysis. Once the homogeneous water masses were identified for each year, water masses of approximately the same location were compared across years for long-term trends. The long-term trends using homogeneous water masses were calculated using ANOVA and regression techniques similar to the long-term trends based on all the data from each research cruise.

Annual Means and Ranges

Table 8.3 presents the annual means and standard deviations for eight variables sampled in twelve different years spanning 1954 to 1980. Although some long-term trends are evident from these means, this type of analysis is inappropriate for identifying trends. Composite analysis of annual data has two major short-comings. The first is that research cruises conducted in each year are unlikely to cover the same seasonal span. The temperature data in the Lake Huron historical database indicate that this has occurred in the Lake Huron sampling. Conceptually, long-term trends in temperature are not realistic. Thermal budgets of the Great Lakes are primarily controlled by insolation, wind stress, and water column depth (Sundaram 1973). Seasonal fluctuations in the thermal regime of Lake Huron could be expected, but on the average the thermal cycle should not have a long-term trend (Sundaram 1973). The annual differences observed in mean temperatures in Table 8.3 are a reflection of the experimental design changing among years. Warm annual averages with small standard deviations (1967) indicate sampling programs concentrating in the summer months and collecting most of the samples from the epilimnion. Cold annual temperatures with large standard deviations (1980) reflect a broader sampling program, both seasonally and spatially.

The second problem associated with identifying long-term trends from annual means is the areal inconsistency of the sampling programs across the years. Some studies have been confined mostly to the nearshore (1970), while others include the entire lake (1968, 1969, 1971, 1972, 1973, and 1980). An example of this effect can be seen in Table 8.3. The mean 1966 conductivity reading is 135 µmho/cm, which is considerably lower than the other annual means.

Table 8.3. Annual means and standard deviations from Lake Huron historical database. Data for April, May, July, August, and September.

Year	Temperature °C	Conductivity µmho/cm	Chloride mg/L	Sulfate mg/L	Silica $mgSiO_2/L$	Nitrate mgN/L	Soluble P µgP/L	Total P µgP/L
1954	12.1(5.8)	166(14)			2.2(0.4)			
1956	12.0(5.2)	177(9)	6.5(2.2)	12.7(2.4)	2.0(0.4)			
1966	14.6(6.2)	135(31)		14.3(2.4)	2.4(1.9)		2.7(1.4)	
1967	17.8(3.9)	173(13)	7.8(0.8)	17.4(0.6)	1.4(0.5)		1.6(2.6)	
1968	11.5(6.1)	200(15)	6.2(2.1)	17.1(1.5)	1.2(0.4)	.21(.06)	0.5(2.6)	7.6(7.1)
1969	9.0(5.2)	184(39)	4.6(2.8)	11.5(6.0)	0.9(0.4)	.20(.05)	0.8(1.6)	6.8(2.6)
1970	15.5(5.2)	208(25)	6.7(2.7)	11.4(1.4)	1.1(0.3)	.13(.06)	3.4(3.6)	
1971	8.5(5.7)	204(16)	5.4(1.1)	14.5(2.2)	1.2(0.4)	0.23(0.04)	0.5(0.3)	4.9(3.8)
1972	7.3(5.2)	203(22)	5.7(2.3)		1.3(0.3)		0.5(0.6)	6.5(6.3)
1973	8.0(5.9)	206(24)	5.5(0.7)		1.4(0.4)	0.25(0.05)	2.5(6.9)	9.6(5.4)
1974	6.9(6.9)	200(29)	5.6(1.5)	14.0(3.2)	1.5(0.6)	.28(0.5)	1.7(1.7)	5.7(3.7)
1980	6.5(5.4)	190(19)	5.1(0.7)	15.1(1.6)	1.4(0.4)	.27(.04)	0.8(.4)	5.2(2.5)

This lower mean is more a function of the location sampled (near Manitoulin Island) than an unusual year. The spatial and seasonal incompatibilities across years prevented any analysis for long-term trends using annual means.

Annual ranges for nine variables were fairly similar between 1974 and 1980 (Table 8.4). These two sampling programs covered the same seasons (April to November) and all of offshore Lake Huron. Changes in the annual range suggest changes in processes occurring within Lake Huron. For example, a large chlorophyll range indicates large algal blooms occurred sometime during the year. Large nutrient ranges imply high nutrient loadings at some time during the year and periods of nutrient depletion at other times.

The ranges in Table 8.4 provide several ecological inferences in regard to differences between 1974 and 1980. The temperature ranges were similar for 1974 and 1980 at 20.6°C and 21.9°C, respectively. This suggests the two surveys were conducted across similar seasons. The conductivity and chloride ranges were different between 1974 and 1980. The 1974 study tended to sample more in the mouth of Saginaw Bay and thus had higher conductivity and chloride maximum values. If one assumes that similar station patterns and densities were sampled in 1974 and 1980, the higher ranges in the 1974 study for all dissolved nutrients (chloride, sulfate, silica, and soluble phosphate) and chlorophyll could suggest a reduction in nutrient loadings and algal growth in 1980 as compared to 1974. However, different stations were sampled in these two years, and it is difficult to infer long-term trends by comparing ranges for only two years. Annual ranges in this case are of little use; only if more data on annual ranges are collected from the same locations can these ranges be useful in inferring the nutrient conditions in Lake Huron.

Table 8.4. Minimum, maximum, and ranges from 1974 and 1980 Lake Huron surveys.

	1974			1980		
Variable	Min.	Max.	Range	Min.	Max.	Range
Temperature	1.0	21.6	20.6	0.7	22.6	21.9
Conductivity	89.	322.	233.	86.	253.	167.
Chloride	1.3	20.2	18.9	1.3	9.0	7.7
Sulfate	3.5	27.0	23.5	2.8	21.2	18.4
Silica	0.1	3.5	3.4	0.6	2.7	2.1
Nitrate	0.181	0.838	0.657	.033	.765	.732
Sol. Phosphorus	<0.1	17.5	17.4	0.1	9.0	8.9
Total Phosphorus	<0.1	42.0	41.9	2.0	58.1	56.1
Chlorophyll	0.1	16.3	16.2	0.8	10.0	9.2

Long-Term Trends

The effect of seasonality on nutrient concentrations in Lake Huron is large and statistically significant (Chapter Four, Appendix A, Schelske _et al_. 1980). This effect can be removed either statistically or by using the database for each season (Richards 1981b). This latter approach was taken in the trend analysis; spring and summer data were analyzed individually. The spring data include those collected in April and May while the summer data include those from the cruises during July, August, and September.

The initial null hypothesis tested for each of the eight variables separately was that there was no difference among years versus the alternative that significant differences exist among years. This hypothesis was tested with one-way ANOVA with unequal sample sizes (Winer 1971). The results (Table 8.5) show that all variables were significantly different among years at the less than 0.1% probability limit. The statistical significance of temperature varying across years implies differences in experimental design for the different studies. Seasonal factors should be fairly small, because this analysis considered studies from only April and May. The differences in temperature across years suggests that some studies may have taken a larger proportion of samples from the nearshore zone than other studies. The total sums of squares are compared in Table 8.6 for cases where the Lake Huron historical database was analyzed using all the data, the spring data only, and one water mass from the spring months only. The total sums of squares were reduced significantly when only the spring months were analyzed compared to the full-year data. Therefore, the long-term trends developed from the spring data have excluded a large portion of variation due to seasonality.

Table 8.5. ANOVA tables for Lake Huron spring data. Each analysis included all data collected from the months of April and May. The ANOVA tables are decomposed into linear and quadratic trends.

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
TEMPERATURE				
Years	569.3	4	142.3	43.4
Linear Trend	330.2	1	330.2	98.4
Lack of fit	239.1	3	79.7	24.2
Quadratic	1.7	1	1.7	0.5
Lack of fit	237.4	2	118.7	36.0
Error	9558.4	2917	3.3	
Total	10128	2921		
CONDUCTIVITY				
Years	204070	4	51017	91.3
Linear trend	136880	1	136880	234.1
Lack of fit	67190	3	22396.7	40.1
Quadratic	9238.2	1	9238.2	16.3
Lack of fit	57951.8	2	28975.9	51.8
Error	1414100	2530	559.0	
Total	1618200	2534		
CHLORIDE				
Years	146.5	4	36.6	9.3
Linear Trend	68.3	1	68.3	17.4
Lack of fit	78.2	3	26.1	6.6
Quadratic	12.7	1	12.7	3.2
Lack of fit	65.5	2	32.8	8.3
Error	5162.9	1313	3.93	
Total	5309.4	1317		
SULFATE				
Years	79.7	2	39.8	6.9
Linear trend	0.1	1	0.1	0.0
Lack of fit	79.6	1	79.6	13.7
Quadratic	79.6	1	79.6	13.7
Lack of fit				
Error	5277.6	909	5.8	
Total	5357.3	911		

(Continued)

Table 8.5. (Concluded).

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
SOLUBLE SILICA				
Years	40.2	4	10.0	98.6
Linear trend	0.2	1	0.2	1.7
Lack of fit	40.0	3	13.3	133.3
Quadratic	37.1	1	37.1	360.0
Lack of fit	2.9	2	1.5	14.5
Error	238.8	2346	0.1	
Total	279.0	2350		
NITRATE-NITROGEN				
Years	0.470	3	0.157	90.2
Linear Trend	0.370	1	0.370	213.2
Lack of fit	0.100	2	0.050	28.9
Quadratic	0.0999	1	0.0999	57.6
Lack of fit	0.0001	1	0.0001	0.1
Error	3.49	2011	0.00173	
Total	3.96	2014		
SOLUBLE PHOSPHATE				
Years	1113.7	4	278.4	80.4
Linear trend	3.1	1	3.1	0.8
Lack of fit	1110.6	3	370.2	105.8
Quadratic	251.4	1	251.4	71.8
Lack of fit	859.2	2	429.6	122.7
Error	7870.5	2272	3.5	
Total	8984.2	2276		
TOTAL PHOSPHORUS				
Years	1453	4	363.3	22.5
Linear trend	2.1	1	2.1	0.1
Lack of fit	1450.9	3	483.6	29.9
Quadratic	940	1	940	57.4
Lack of fit	510.9	2	255.5	15.8
Error	37177	2299	16.2	
Total	38630	2303		

Table 8.6. Total sums of squares from one-way ANOVA for eight variables considered in five separate analyses: entire year, spring months only, summer months only, and one homogeneous water mass from spring months or summer months.

Variable	Full Year	Spring	One Water Mass Spring	Summer	One Water Mass Summer
Temperature	365490	10128	1125.6	143960	40921
Conductivity	5292100	1618200	89965	1628900	251690
Chloride	11859	5309.4	37.9	2933.6	245.6
Sulfate	15623	5357.3	108.6	5949.3	1198.9
Soluble Silica	2039.6	278.99	18.6	1203.6	261.3
Nitrate	15.1	3.96	1.66	7.10	1.33
Soluble Phosphate	14306	8984.2	7477.3	4950.7	1087.7
Total Phosphorus	109060	38360	2152.8	32048	3582.7

Spring - All Data

Least-squares regression was used to determine whether or not a significant linear trend existed for any of the eight variables between the years 1971 and 1980. Temperature, conductivity, chloride, and nitrate had a significant linear trend (0.1 level of significance) (Table 8.7 and Fig. 8.1). Sulfate, soluble reactive silica, soluble reactive phosphorus, and total phosphorus had no significant long-term linear trend, but each had a significant curvilinear trend (Fig. 8.1). Mean concentrations of sulfate decreased between 1974 and 1977 and increased after 1977. Those for silica increased between 1971 and 1976 and decreased after 1976. Mean concentrations of soluble reactive and total phosphorus increased between 1971 and 1976 and decreased after 1976.

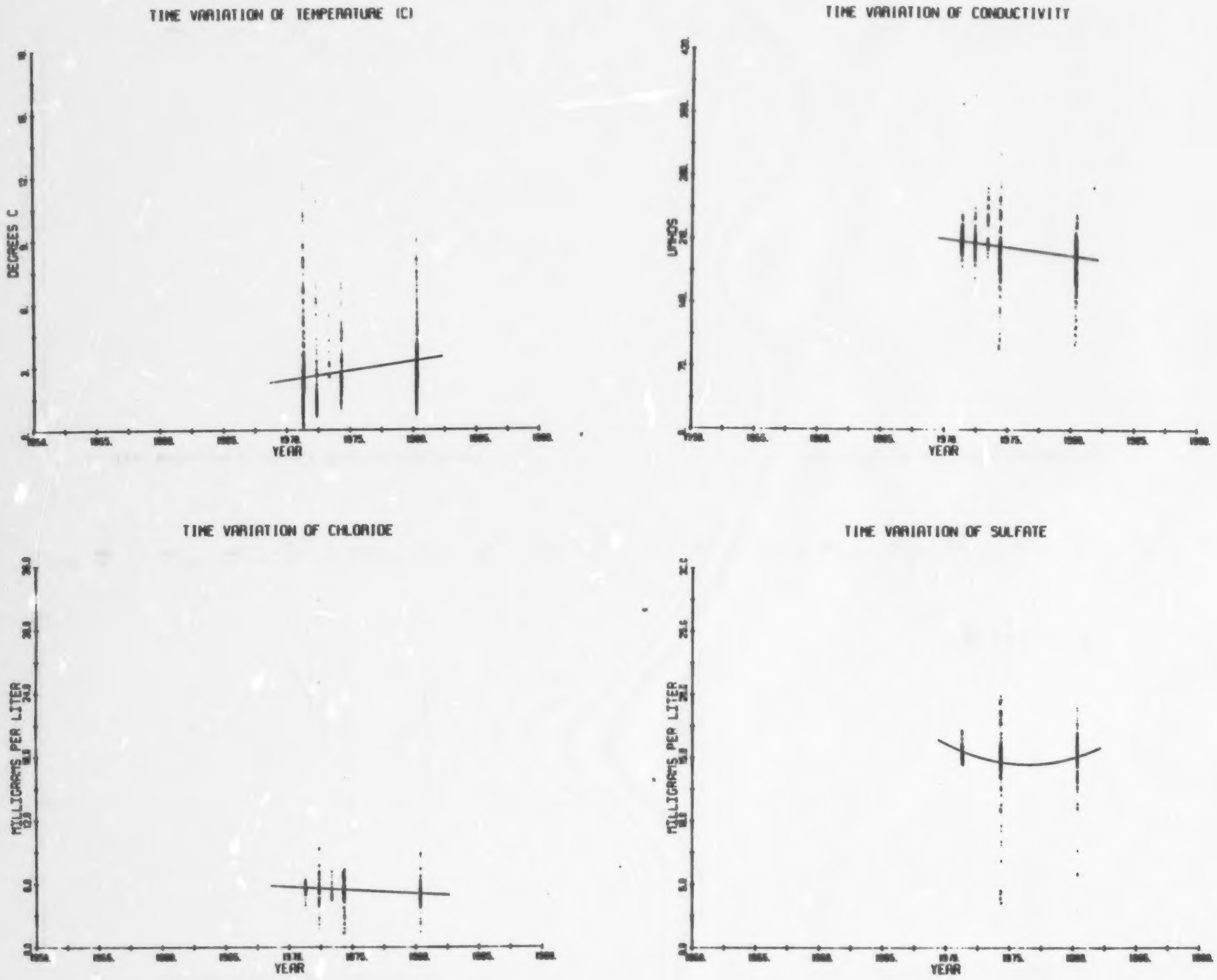
Spring - One Homogeneous Water Mass

The problem of inconsistent experimental designs across years is both seasonal and spatial. The approach of using only spring data removes many of the seasonal differences, but it does not remove any spatial differences. The technique of identifying homogeneous water masses developed in Chapter Six was applied to the historical database. The objective was to generate one or more homogeneous water masses that were compared across years. The technique used was cluster analysis of surface samples to identify the water masses. Discriminant functions analysis was then used to confirm whether or not the identified clusters were statistically distinct from one another within each year. The final result was that one water mass per year was identified as representing open southern Lake Huron water quality. In this manner, spatial differences in the sampling program were reduced across the study years.

Table 8.7. Linear regression coefficients from least squares analysis of spring and summer month data.

Variable	All Stations Spring (1971-1980)	One Water Mass Representing Southern Lake Huron Spring (1971-1980)	All Stations Summer (1954-1980)	One Water Mass Summer (1954-1980)	Epilimnion One Water Mass Summer (1954-1980)
Temperature °C/yr.	0.0898	0.144	-0.0721	-0.1350	-0.0659
Conductivity µmho/cm/yr.	-1.845	-0.436	1.10	1.6164	1.30
Chloride mg/L/yr.	-0.0622	0.0249	-0.0608[1]	-0.0180[1]	-0.0370[1]
Sulfate mg/L/yr.	n.s.	0.0518	0.116[1]	0.1290[1]	0.112[1]
Silica mg/L/yr.	n.s.	n.s.	-0.0397	-0.0418	-0.0493
Nitrate mg/L/yr.	0.0033	0.00888	0.00624[2]	0.0066[2]	0.00488[2]
Sol. P µg/L/yr.	n.s.	n.s.	0.0296[3]	0.0690[3]	n.s.[3]
Total P µg/L/yr.	n.s.	0.153	-0.0885[2]	n.s.[2]	n.s.[2]

[1] 1956-1980
[2] 1968-1980
[3] 1966-1980



TIME VARIATION OF TEMPERATURE (C)

TIME VARIATION OF CONDUCTIVITY

TIME VARIATION OF CHLORIDE

TIME VARIATION OF SULFATE

Figure 8.1. Time variation of various parameters for all Lake Huron spring water data.

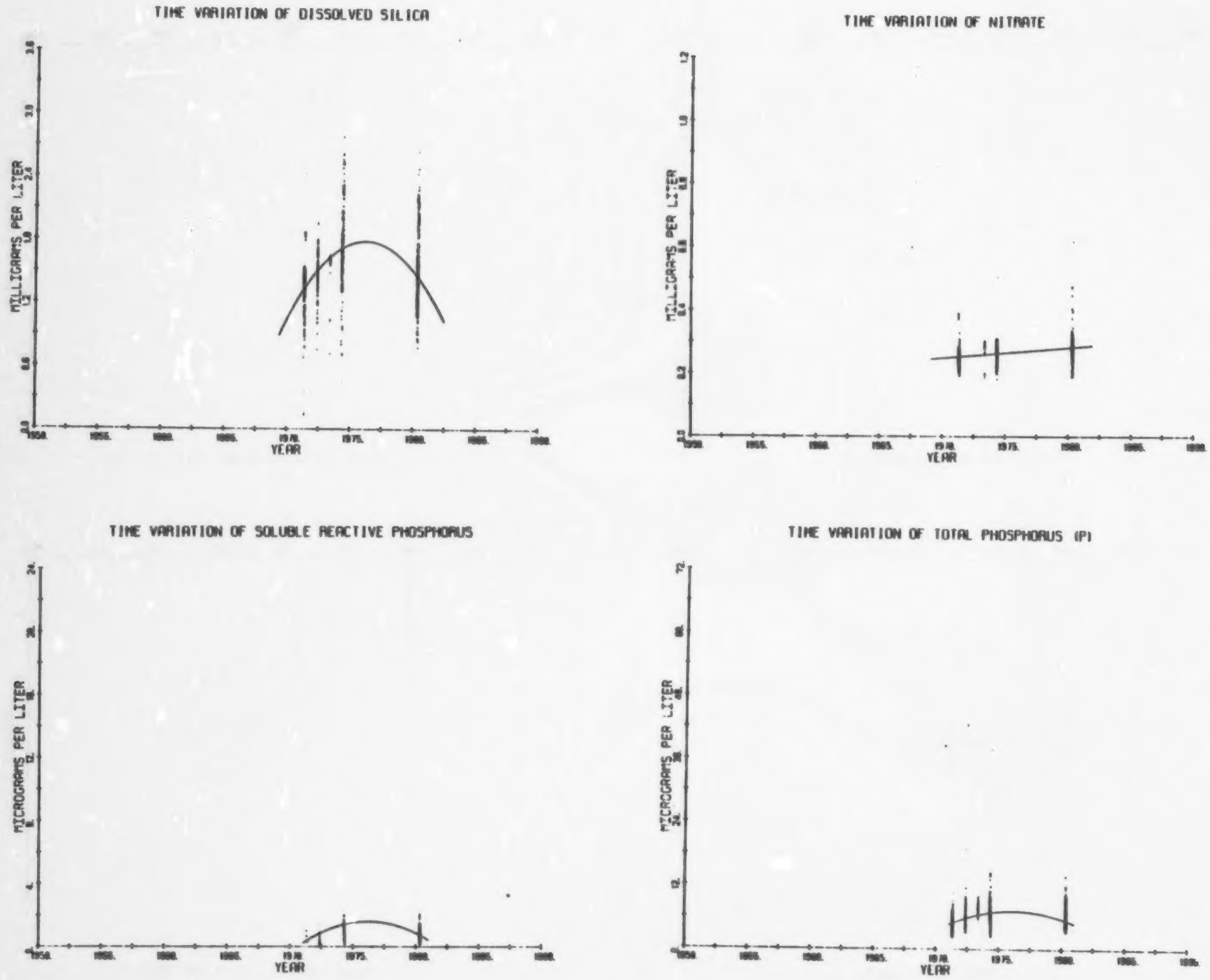


Figure 8.1. Concluded.

The identification of homogeneous water masses was less than perfect in that a few years actually had their water masses located more toward the northern end of Lake Huron (1966). Table 8.6, nonetheless, shows a considerable reduction in the sums of square between the spring month analyses and the one water mass analyses. The objective of decreasing the overall variance in the long-term trend analysis was achieved.

The same hypotheses were tested for the one water mass data as for the spring month data. First, do variables differ significantly across years (ANOVA)? Second, is there a long-term linear trend (Regression)? The results of these analyses in Table 8.8 show that the inferences using the one water mass data are almost the same as using all of the spring data. All eight variables changed significantly across the 1971 to 1980 period (Table 8.8).

The regression analysis using the one water mass data results were somewhat similar to the results using all of the spring data (Table 8.7). Nitrate and temperature continued to show an increasing trend, and conductivity showed a decreasing trend for both data sets. Unlike all of the spring data, one water mass data for sulfate and total phosphorus showed an increasing trend. Only chloride showed a major change in the regression coefficient using the one water mass data. In this case, a decrease was noted for all spring data, while an increase was found for the spring one water mass data. The difference may perhaps be due to the inclusion of data collected from the nearshore zone or from an emphasis on southern Lake Huron data in the second case. Six of the eight variables showed significant linear trends over the 10 years, with soluble phosphate and soluble reactive silica displaying no linear trend (Fig. 8.2). However, both displayed a curvilinear variation (Fig. 8.2). Both increased between 1971 and 1976 and decreased after 1976. All curvilinear fits displayed

Table 8.8. ANOVA tables for Lake Huron spring data using one homogeneous water mass from each cruise. The ANOVA tables are decomposed into linear and quadratic trends.

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
TEMPERATURE				
Years	181.9	4	45.5	24.3
Linear Trend	128.3	1	128.3	68.6
Lack of fit	53.6	3	17.9	9.6
Quadratic	8.3	1	8.3	4.4
Lack of fit	45.3	2	22.7	12.1
Error	943.8	504	1.9	
Total	1125.6	508		
CONDUCTIVITY				
Years	40263	4	10066	86.9
Linear trend	1195	1	1195	10.3
Lack of fit	39068	3	13023	112.4
Quadratic	3956	1	3956	34.1
Lack of fit	35112	2	17556	151.5
Error	49702	429	116	
Total	89965	433		
CHLORIDE				
Years	9.65	4	2.41	17.4
Linear Trend	1.70	1	1.70	12.1
Lack of fit	7.95	3	2.65	18.9
Quadratic	5.98	1	5.98	42.7
Lack of fit	1.97	2	0.99	7.1
Error	28.3	204	0.14	
Total	38.0	208		
SULFATE				
Years	18.4	2	9.2	15.4
Linear trend	6.5	1	6.5	10.8
Lack of fit	11.9	1	11.9	19.8
Quadratic	11.9	1	11.9	14.5
Lack of fit				
Error	90.2	151	0.60	
Total	108.6	153		

(continued)

Table 8.8. (Concluded).

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
SOLUBLE SILICA				
Years	7.73	4	1.93	76.3
Linear trend	0.09	1	0.09	3.6
Lack of fit	7.64	3	2.55	102.0
Quadratic	7.62	1	7.62	304.8
Lack of fit	0.02	2	0.01	0.4
Error	10.8	428	0.025	
Total	18.6	432		
NITRATE-NITROGEN				
Years	0.48	3	0.16	53.1
Linear Trend	0.47	1	0.47	156.7
Lack of fit	0.1	2	0.05	16.7
Quadratic	0.0005	1	0.0005	0.2
Lack of fit	0.0005	1	0.0005	0.2
Error	1.18	387	0.003	
Total	1.66	390		
SOLUBLE PHOSPHATE				
Years	1509.2	4	377.3	25.9
Linear trend	1.2	1	1.2	0.1
Lack of fit	1508.0	3	502.7	34.4
Quadratic	133.0	1	133.0	9.1
Lack of fit	1375.0	2	687.5	47.1
Error	5968.0	410	14.6	
Total	7477.3	414		
TOTAL PHOSPHORUS				
Years	415.8	4	104.0	25.5
Linear trend	142.6	1	142.6	34.8
Lack of fit	273.2	3	91.1	22.2
Quadratic	56.9	1	56.9	13.9
Lack of fit	216.3	2	108.2	26.4
Error	1737.	426	4.1	
Total	2152.8	430		

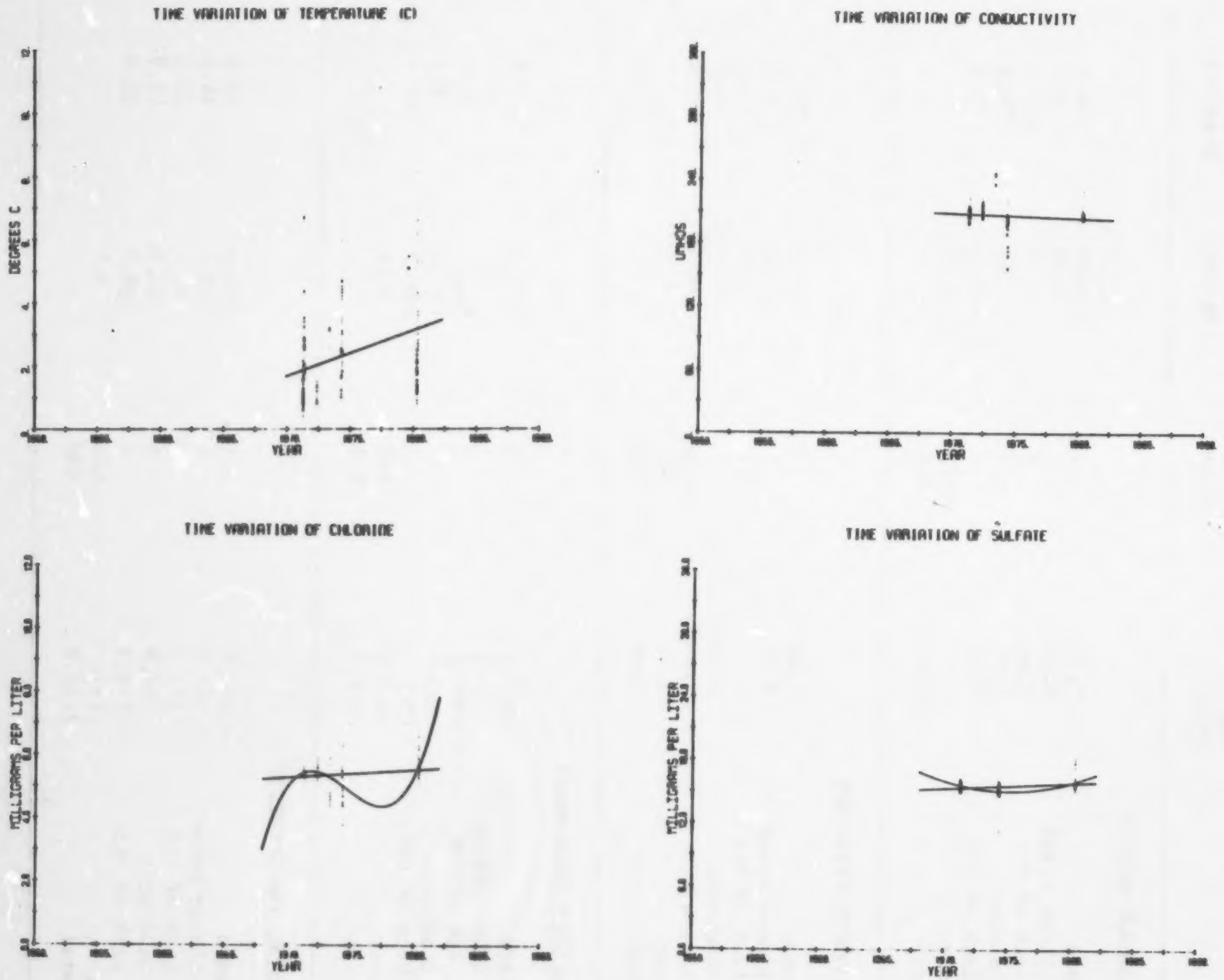


Figure 8.2. Time variation of various parameters for Lake Huron spring one water mass data.

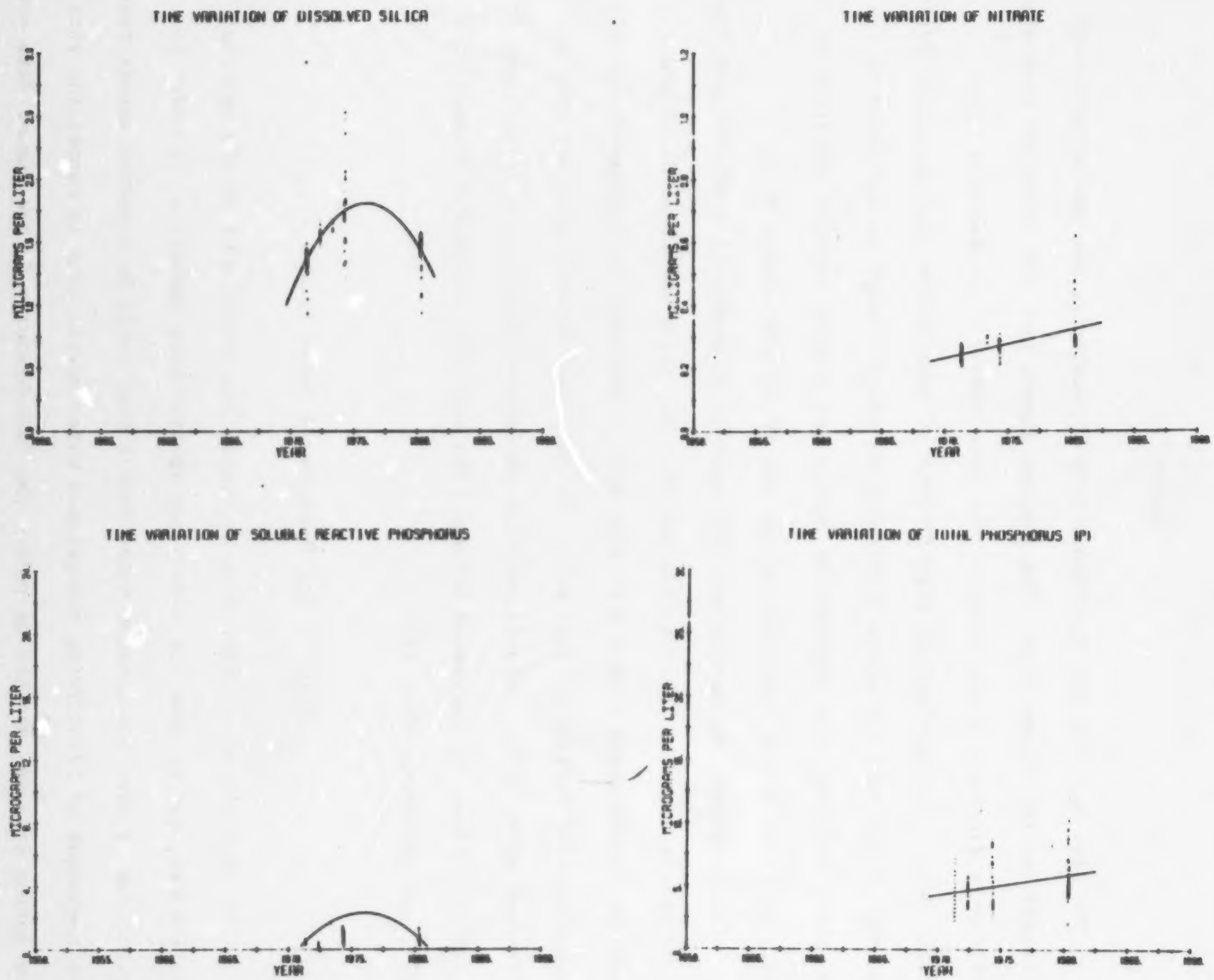


Figure 8.2. Concluded.

in spring for one homogeneous water mass resemble those shown in spring for the entire lake.

Summer

The same approach and hypotheses used in analyzing the spring data were utilized for the summer data. The results showed that all variables were significantly different among years at the less than 0.1% probability limit (Table 8.9). The statistical significance of temperature varying across years for the summer data was again attributed to sample design as discussed in the preceding section. The analysis by season has greatly reduced variation in the data, as shown by the reduction of the sum of squares (Table 8.6).

Least-squares regression was also used to determine if a significant linear trend existed for the 1954 to 1980 period. All eight variables displayed a significant linear trend (Table 8.7, Fig. 8.3). Conductivity displayed a significant 2nd order variation (Fig. 8.3). It increased between 1954 and 1970 and decreased after 1970. Soluble reactive phosphorus displayed a significant 3rd order variation. It decreased between 1966 and 1970, increased between 1970 and 1977, and decreased after 1977.

Summer - One Homogeneous Water Mass

The analysis of nutrient data by season can remove many of the seasonal differences, but it does not reduce any spatial heterogeneity. In order to select one or more homogeneous water masses that could be compared across years, the technique of identifying homogeneous water masses used in connection with the spring data was applied to reduce the heterogeneity in the summer data set.

Table 8.9. ANOVA tables for Lake Huron summer data. Each analysis included all data collected from the months of July, August, and September. The ANOVA tables are decomposed into linear and quadratic trends.

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
TEMPERATURE				
Years	6848.1	11	622.6	19.5
Linear Trend	1066.0	1	1066.0	33.4
Lack of fit	5782.1	10	578.2	18.1
Quadratic	83.6	1	83.6	2.6
Lack of fit	5698.5	9	633.2	19.8
Error	137110	4304	31.9	
Total	143960	4315		
CONDUCTIVITY				
Years	777080	11	70643	334.3
Linear trend	281100	1	281100	1330.3
Lack of fit	495980	10	49598	234.7
Quadratic	326770	1	326770	1546.5
Lack of fit	169210	9	18801.1	89.0
Error	851800	4031	211.3	
Total	1709100	4042		
CHLORIDE				
Years	458.8	8	57.4	42.4
Linear trend	245.7	1	245.7	175.5
Lack of fit	213.1	7	30.4	21.7
Quadratic	15.0	1	15.0	10.7
Lack of fit	198.1	6	33.0	23.6
Error	2474.7	1829	1.4	
Total	2933.6	1837		
SULFATE				
Years	2250.1	7	321.4	95.6
Linear trend	876.8	1	876.8	257.9
Lack of fit	1373.3	6	228.9	67.3
Quadratic	120.7	1	120.7	35.5
Lack of fit	1252.6	5	250.5	73.7
Error	3699.2	1100	3.4	
Total	5949.3	1107		

(Continued)

Table 8.9. (Concluded).

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
SOLUBLE SILICA				
Years	553.6	11	50.3	264.2
Linear trend	365.1	1	365.1	1825.5
Lack of fit	188.50	10	18.8	94.2
Quadratic	123.3	1	123.3	616.5
Lack of fit	65.2	9	7.2	36.2
Error	650.0	3412	.2	
Total	1203.6	3423		
NITRATE-NITROGEN				
Years	2.7926	6	0.46544	224.2
Linear trend	1.6642	1	1.6642	792.5
Lack of fit	1.1284	5	0.2257	107.5
Quadratic	0.0052	1	0.0052	2.5
Lack of fit	1.1232	4	0.2808	133.7
Error	4.3083	2075	0.0021	
Total	7.1009	2081		
SOLUBLE PHOSPHATE				
Years	1346.9	9	149.7	101.9
Linear trend	36.3	1	36.3	24.2
Lack of fit	1310.6	8	163.8	109.2
Quadratic	116.5	1	116.5	77.7
Lack of fit	1194.1	7	170.6	113.7
Error	3603.8	2453	1.5	
Total	4950.7	2462		
TOTAL PHOSPHORUS				
Years	3438.3	6	573.05	43.3
Linear trend	275.4	1	275.4	20.9
Lack of fit	3162.9	5	632.6	47.9
Quadratic	18.6	1	18.6	1.4
Lack of fit	3144.3	4	786.1	59.6
Error	28610	2162	13.2	
Total	32048	2168		

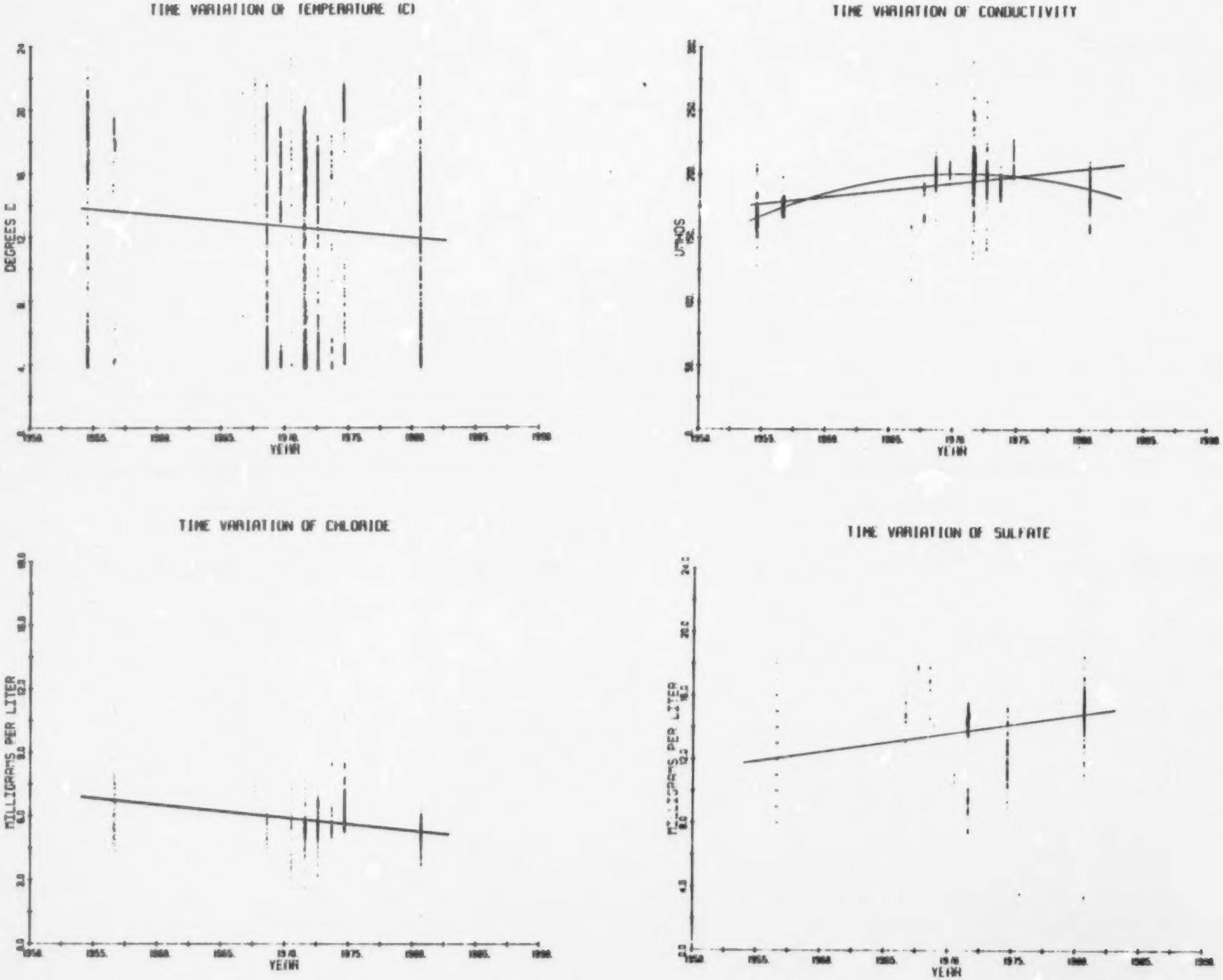


Figure 8.3. Time variation of various parameters for all Lake Huron summer water data.

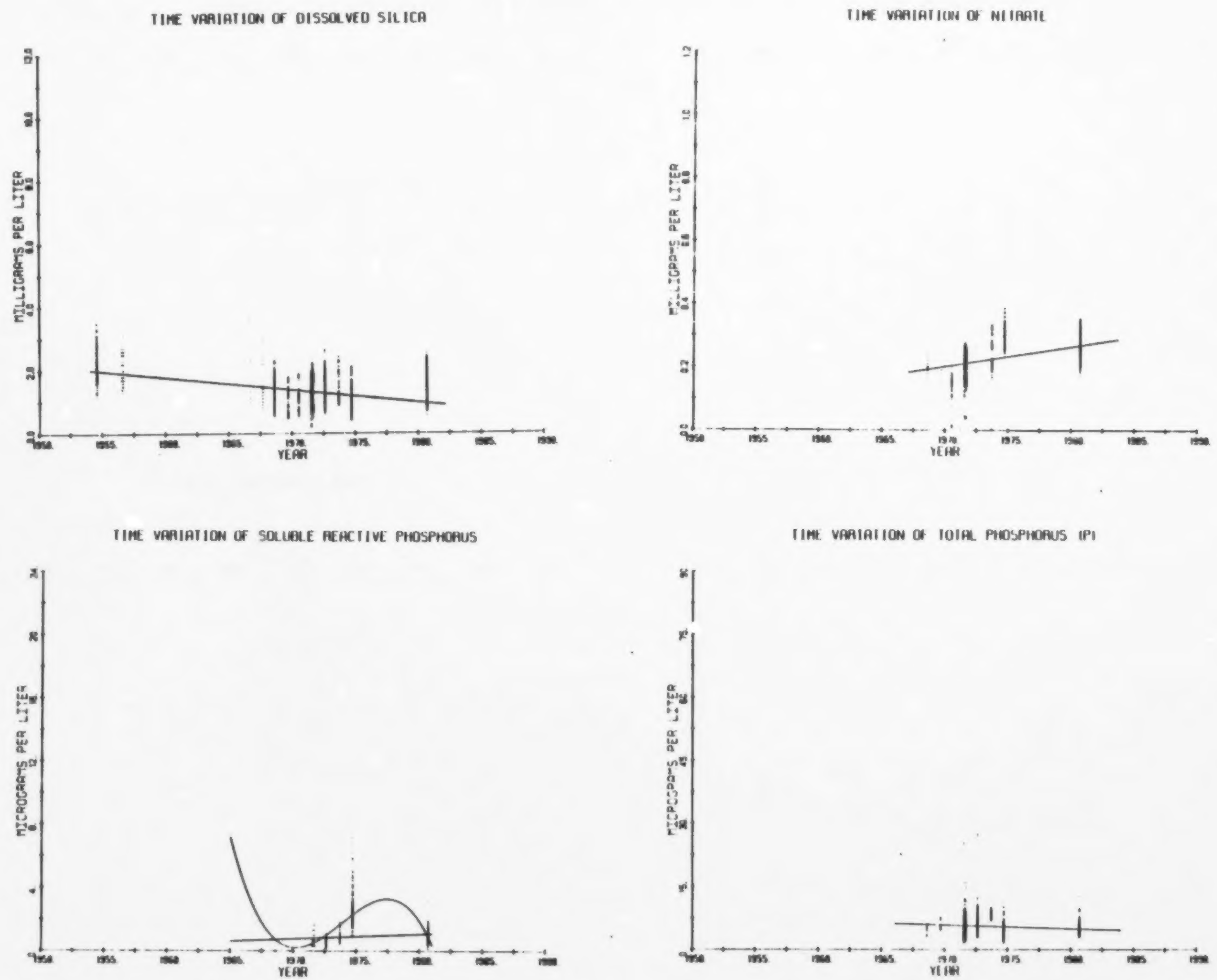


Figure 8.3. Concluded.

However, spatial heterogeneity occurs not only horizontally but also vertically in summer. Vertical differences often are larger and more distinct than the horizontal differences. In order to identify a water mass which is homogeneous both vertically and horizontally, an epilimnetic portion of the homogeneous water mass was selected for use in the analysis. The epilimnion is defined as the surface to 5 m in depth. The comparison shown below, however, included the results from both one water mass and only the epilimnetic portion of the water mass. The result showed a considerable reduction of the sums of squares between the summer month analysis and the one water mass analysis and between the one water mass and the epilimnetic portion of the water mass (Table 8.6). This indicates that the technique applied has been successful in reducing the variation in the data. However, it is also noted that such a selection has reduced the sample size in the data set of the epilimnetic portion of the water mass.

The hypotheses used for the spring data were tested for the summer one water mass data. All eight variables changed significantly between 1954 and 1980 (Table 8.10). The regression coefficients derived from both the one water mass and the epilimnetic portion of the water mass were quite similar to those from the whole summer data set (Table 8.7). For the one water mass subsetting of the data, all but total phosphorus displayed significant linear trends. The signs of the regression coefficients generated from either one water mass or the epilimnetic portion of the water mass were identical to those from all of the stations' summer data. The magnitude of the coefficients was also very similar between these data sets. Like those of spring, the trends are small but statistically significant. These changes were smaller than those reported from Lakes Erie and Michigan (Beeton 1969). For the epilimnion one water mass

Table 8.10. ANOVA tables for Lake Huron summer data using one homogeneous water mass from each cruise. The ANOVA tables are decomposed into linear and quadratic trends.

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
TEMPERATURE				
Years	5875.0	11	534.1	15.1
Linear trend	888.7	1	888.7	25.1
Lack of fit	4986.3	10	498.6	14.1
Quadratic	1445.7	1	1445.7	40.8
Lack of fit	3540.6	9	393.4	11.1
Error	35046	990	35.4	
Total	40921	1001		
CONDUCTIVITY				
Years	215990	11	19635	515.9
Linear trend	141780	1	141780	3721.3
Lack of fit	74210	10	7421	194.8
Quadratic	12640	1	12640	331.8
Lack of fit	61570	9	6841.	179.6
Error	35700	938	38.	
Total	251690	949		
CHLORIDE				
Years	65.4	8	8.2	18.1
Linear trend	5.2	1	5.2	11.6
Lack of fit	60.2	7	8.6	19.1
Quadratic	1.0	1	1.0	2.2
Lack of fit	59.2	6	9.9	22
Error	180.2	398	0.45	
Total	245.6	406		
SULFATE				
Years	835.1	7	119.3	81.0
Linear trend	262.1	1	262.1	178.3
Lack of fit	573.0	6	95.5	65.0
Quadratic	7.2	1	7.2	4.9
Lack of fit	565.8	5	113.2	77.0
Error	363.8	247	1.47	
Total	1199	254		

(continued)

Table 8.10. (Concluded).

	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic
SOLUBLE SILICA				
Years	128.5	11	11.7	74.1
Linear trend	94.8	1	94.8	592.5
Lack of fit	33.7	10	3.4	21.1
Quadratic	17.1	1	17.1	106.9
Lack of fit	16.6	9	1.8	11.5
Error	132.8	842	0.16	
Total	261.3	853		
NITRATE-NITROGEN				
Years	.526	6	0.877	54.5
Linear trend	.271	1	0.271	169.4
Lack of fit	.255	5	0.051	31.9
Quadratic	0.0	1	0.0	0.0
Lack of fit				
Error	.803	499	0.0016	
Total	1.33	505		
SOLUBLE PHOSPHATE				
Years	395.6	9	44.0	32.2
Linear trend	30.8	1	30.8	22.0
Lack of fit	364.8	8	45.6	32.6
Quadratic	23.1	1	23.1	16.5
Lack of fit	341.7	7	48.8	34.9
Error	692.0	507	1.4	
Total	1087.7	516		
TOTAL PHOSPHORUS				
Years	987.3	6	164.6	31.6
Linear trend	0.1	1	0.1	0.0
Lack of fit	987.2	5	197.4	38.0
Quadratic	2.6	1	2.6	0.5
Lack of fit	984.6	4	246.2	47.3
Error	2595.4	498	5.2	
Total	3582.7	504		

of summer, linear trends were significant for temperature, conductivity, chloride, sulfate, dissolved silica, and nitrate (Table 8.7, Fig. 8.4). Four variables were best described by curvilinear fits (Fig. 8.4). Temperature decreased between 1954 and 1966 and increased after 1966. Sulfate increased between 1956 and 1962, decreased between 1962 and 1975, and increased after 1975. Soluble reactive phosphorus decreased between 1966 and 1970, increased between 1970 and 1977, and decreased after 1977. Total phosphorus decreased between 1968 and 1977, and increased after 1977.

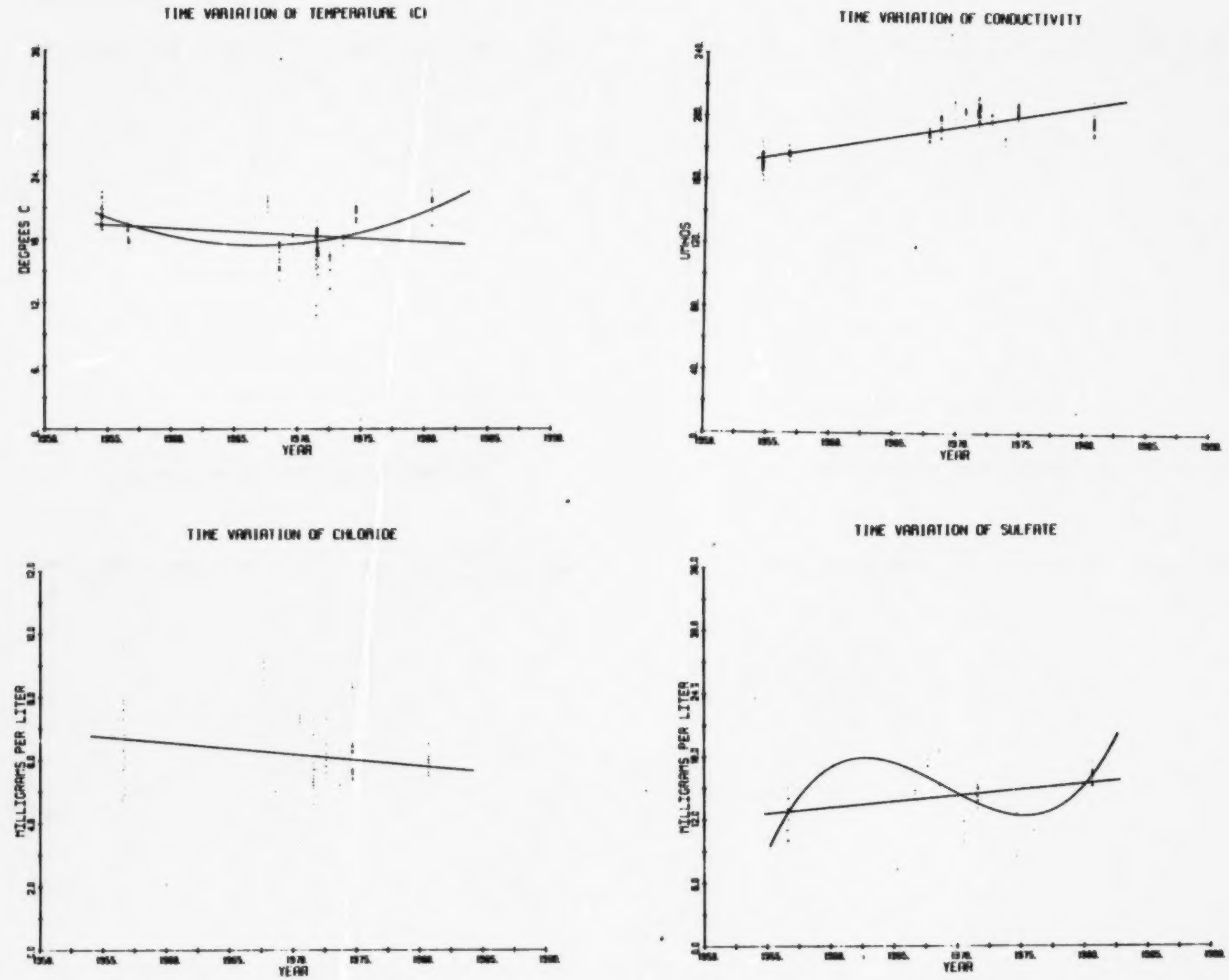


Figure 8.4. Time variation of various parameters for Lake Huron summer epilimnion one water mass data.

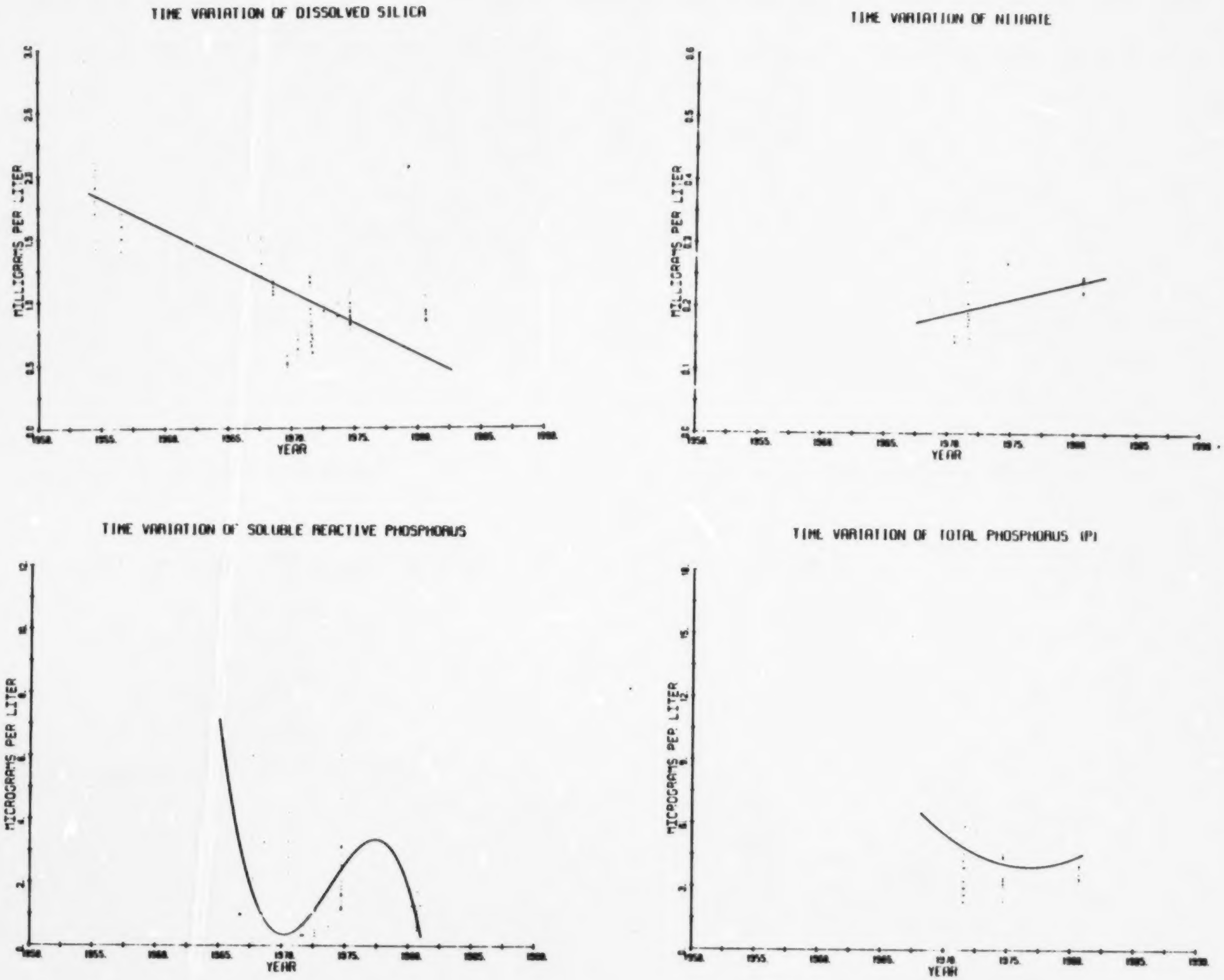


Figure 8.4. Concluded.

Conclusions

Long-term changes in the chemistry of Lake Huron waters have been identified using the results of twelve studies spanning a 26-year period of observations. As might be expected of a dynamic system lake, Lake Huron long-term trends are complex. For roughly one-half of the parameters investigated, changes over the 26 years were curvilinear or oscillatory. Of these, one-half had a linear trend superimposed over the oscillations. For each of the various ways we manipulated the data base, sulfate and nitrate were found to increase. For the majority of cases, dissolved silica and chloride decreased. Sulfate increased at a rate of 0.05 to 0.13 mg/L/yr or 0.3 to 0.8% of the 1980 mean concentration per year. Nitrate increased at a rate of 0.0030 to 0.0089 mg/L/yr or 1.1 to 3.1% per year. Dissolved silica decreased at a rate of 0.040 to 0.049 mg/L/yr or 2.8 to 3.6% of the 1980 mean per year. Chloride decreased at a rate of 0.02 to 0.06 mg/L/yr or 0.4 to 1.2% of the 1980 mean per year. All four parameters should continue to be monitored.

For those parameters which showed reversals in trend over the period of observation, reversals consistently occurred in the mid-1970s. It is unfortunate that data were not available for this critical period of time. Since the mid-1970s, dissolved reactive silica and soluble reactive phosphorus have decreased, and nitrate and sulfate have increased. Changes in long-term trends could be or have been attributed to factors such as changes in sampling and analytical methods, reduction in anthropogenic inputs from the major point sources, and differences in biological utilization of these elements. Despite the changes which have occurred in Lake Huron between 1954 and 1980, Lake Huron remains an oligotrophic lake.

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APPENDIX A

COMPARISON OF SURFACE/EPILIMNION TO LOWER LAYER/HYPOLIMNION

Table A-1. Comparison of surface/epilimnion total phosphorus with lower layer/hypolimnion total phosphorus. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

	Cruises					
1974/1980 Areas	1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S	S*	S	S
D		T	S	S	S	S
E		S	S	S	S	
F		T	S	S		
G			S			
I NS-I	T		S	S		
1 WNC		T	S	S	S	
2 CNC		T	S	S*	S	
3a ENC	Ice Cover		S	S	S	
4 A4LH		T	S	S	S	S
5 A5LH		T	S	S	S	
6 NBLH				S*	S	S
7 SBM			S	S	S*	S
8 SBLH			S	S*	S*	S
9			S	S*	S	
10		T	S*	S*	S	
11			T	S	S	S
12				S	S	S
13			T	S	S	S
14		T	S	S	S	
15		S	S	S	S	
16		S	S	S	S	
17 CBGB		T	T	S*	S*	S
18		S	S*	S*		
3			S	S*	S	

Table A-2. Comparison of surface/epilimnion total dissolved phosphorus with lower layer/hypolimnion total dissolved phosphorus. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises 1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S	S	S	S
D		T	S	S	S	S
E		S	S	S	S	
F		T	S	S		
G			S			
I NS-I	T		S	S		
1 WNC		T	S	S	S	
2 CNC		T	S	S	S	
3a ENC	Ice Cover		S	S	S	
4 A4LH		T	S	S	S	S
5 A5LH		T	S	S	S	
6 NBLH				S*	S	S*
7 SBM			S	S	S	S
8 SBLH			S	S*	S*	S
9			S	S	S	
10		T	S	S	S	
11			T	S	S	S
12				S	S	S
13			T	S	S	S
14		T	S	S	S	
15		S	S	S	S	
16		S	S	S	S	
17 CBGB		T	T	S	S	S
18		S	S	S		
3			S	S	S	

Table A-3. Comparison of surface/epilimnion dissolved orthophosphorus with lower layer/hypolimnion dissolved orthophosphorus. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises					
	1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S	S	S	S
D		T	S	S	S	S
E		S	S	S	S	
F		T	S	S		
G			S			
I NS-I	T		S	S		
1 WNC		T	S	S	S	
2 CNC		T	S	S	S	
3a ENC	Ice Cover		S	S	S	
4 A4LH		T	S	S	S	S
5 A5LH		T	S	S	S*	
6 NBLH				S	S*	S*
7 SBM			S	S	S*	S
8 SBLH			S	S	S*	S*
9			S	S	S*	
10		T	S	S	S	
11			T	S*	S	S
12				S	S	S
13			T	S	S	S*
14		T	S	S	S	
15		S	S	S	S	
16		S	S	S	S	
17 CBGB		T	T	S	S*	S
18		S	S	S		
3			S	S	S	

Table A-4. Comparison of surface/epilimnion dissolved reactive silica with lower layer/hypolimnion dissolved reactive silica. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

	Cruises					
1974/1980 Areas	1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S	S*	S	S
D		T	S	S*	S*	S*
E		S	S	S*	S*	
F		T	S	S*	*	
G			S			
I NS-I	T		S*	S*		
1 WNC		T	S	S	S	
2 CNC		T	S	S*	S*	
3a ENC	Ice Cover		S*	S*	S*	
4 A4LH		T	S	S*	S	S
5 A5LH		T*	S	S*	S*	
6 NBLH				S*	S*	S*
7 SBM			S*	S*	S*	S
8 SBLH			S*	S*	S*	S*
9			S	S*	S*	
10		T	S*	S*	S*	
11			T	S*	S*	S
12		*		S*	S*	S
13			T	S*	S*	S*
14		T	S*	S*	S*	
15		S	S	S*	S*	
16		S	S	S	S*	
17 CBGB		T	T	S*	S*	S*
18		S	S	S		
3			S	S	S	

Table A-5. Comparison of surface/epilimnion dissolved nitrate + nitrite with lower layer/hypolimnion dissolved nitrate + nitrite. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises					
	1	2	3	4	5	6
A			S	S	S	
B			S	S	S*	
C		T	S*	S	S*	S
D		T	S	S*	S*	S*
E		S*	S*	S*	S*	
F		T*	S*	S*		
G			S*			
I NS-I	T		S	S*		
1 WNC		T	S*	S*	S*	
2 CNC		T	S*	S*	S*	
3a ENC	Ice Cover		S*	S	S*	
4 A4LH		T	S	S*	S*	S
5 A5LH		T*	S*	S*	S*	
6 NBLH				S*	S*	S*
7 SBM			S	S*	S*	S
8 SBLH			S	S*	S*	S*
9			S	S*	S	
10		T	S*	S*	S	
11			T	S*	S*	S
12				S*	S*	S*
13			T	S*	S*	S*
14		T	S*	S*	S*	
15		S	S*	S*	S*	
16		S	S*	S*	S*	
17 CBGB		T	T*	S*	S*	S*
18		S	S*	S		
3			S	S*	S*	

Table A-6. Comparison of surface/epilimnion dissolved ammonia with lower layer/hypolimnion dissolved ammonia. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises					
	1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S*	S	S	S
D		T	S	S*	S*	S*
E		S	S	S*	S	
F		T	S	S*		
G			S			
I NS-I	T		S	S		
1 WNC		T	S	S*	S	
2 CNC		T	S	S	S	
3a ENC	Ice Cover		S*	S*	S	
4 A4LH		T	S	S*	S	S
5 A5LH		T*	S	S	S	
6 NBLH				S*	S	S
7 SBM			S	S*	S	S
8 SBLH			S	S*	S	S
9			S	S	S	
10		T	S	S	S	
11			T*	S	S	S
12				S*	S	S
13			T	S*	S	S
14		T	S	S*	S	
15		S	S	S*	S	
16		S	S*	S	S	
17 CBGB		T	T	S*	S	S
18		S	S	S		
3			S*	S	S	

Table A-7. Comparison of surface/epilimnion specific conductivity with lower layer/hypolimnion specific conductivity. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas		Cruises					
		1	2	3	4	5	6
A				S	S	S	
B				S	S	S	
C			T	S	S	S	S
D			T	S	S	S	S*
E			S*	S*	S*	S*	
F			T	S	S*	*	
G				S			
I	NS-I	T		S	S*		
1	WNC		T	S*	S*	S*	
2	CNC		T	S*	S*	S*	
3a	ENC	Ice Cover		S	S*	S*	
4	A4LH		T	S*	S	S	S
5	A5LH		T	S*	S	S*	
6	NBLH				S*	S*	S*
7	SBM			S	S*	S*	S
8	SBLH			S	S*	S	S
9				S	S*	S	
10			T	S*	S*	S	
11		*		T	S*	S	S
12					S	S	S
13				T	S*	S	S
14			T	S	S	S	
15			S	S	S	S*	
16			S	S*	S*	S*	
17	CBGB		T	T	S	S*	S
18			S	S*	S*		
3				S	S*	S*	

Table A-8. Comparison of surface/epilimnion alkalinity with lower layer/ hypolimnion alkalinity. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises					
	1	2	3	4	5	6
A			S	S	S	
B			S	S	S*	
C		T	S	S	S*	S
D		T	S	S	S	S
E		S*	S*	S*	S*	
F		T	S*	S*		
G			S			
I NS-I	T		S	S		
1 WNC		T	S*	S*	S*	
2 CNC		T	S*	S*	S*	
3a ENC	Ice Cover		S	S*	S*	
4 A4LH		T	S*	S	S	S
5 A5LH		T	S*	S	S*	
6 NBLH				S*	S*	S
7 SBM			S	S	S*	S
8 SBLH			S	S*	S	S
9			S	S*	S	
10		T	S	S	S	
11			T	S*	S	S
12				S	S	S
13			T	S*	S	S
14	*	T	S	S*	S	
15		S	S	S	S*	
16		S	S*	S*	S	
17 CBGB		T	T	S*	S	S*
18		S	S*	S		
3			S	S*	S	

Table A-9. Comparison of surface/epilimnion pH with lower layer/hypolimnion pH. Average values which differ between the two layers at the 95% confidence level are indicated by *. T indicates the presence of a thermal bar. S indicates thermal stratification.

1974/1980 Areas	Cruises 1	2	3	4	5	6
A			S	S	S	
B			S	S	S	
C		T	S	S	S	S
D		T	S	S*	S	S*
E		S*	S*	S*	S	
F		T	S*	S		
G			S			
I NS-I	T		S	S		
1 WNC		T	S	S*	S	
2 CNC		T	S*	S*	S	
3a ENC	Ice Cover		S*	S*	S	
4 A4LH		T	S	S*	S	S
5 A5LH		T	S	S*	S*	
6 NBLH				S*	S*	S*
7 SBM			S*	S*	S*	S
8 SBLH			S	S*	S*	S*
9			S	S*	S	
10		T	S	S	S*	
11			T	S*	S*	S*
12				S*	S	S
13			T	S*	S	S*
14		T	S	S*	S	
15		S	S	S*	S*	
16		S	S	S	S	
17 CBGB		T	T	S*	S	S
18		S	S	S*		
3			S	S*	S	

APPENDIX B

STATISTICAL SUMMARIES FOR 1974 AND 1980

Table B-1. 1974 and 1980 statistical summaries of nearshore area A epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

Parameter		1974				1980			
		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	5.8	—	12.7	—	6.1	19.8	11.4	11.7
	S	0.9	—	0.4	—	3.3	2.5	0.35	7.0
	Min	4.7	—	11.8	—	2.3	14.5	11.0	2.3
	Max	7.1	—	3.6	—	12.1	22.4	11.6	22.4
	n	12	—	12	—	13	9	3	25
Secchi Depth	$\overline{X}$	1.5	—	2.5	2.2	5.0	8.8	4.0	6.7
	S	1.0	—	1.4	1.3	1.4	1.1	—	2.5
	Min	0.1	—	1.0	0.1	4.0	7.9	4.0	4.0
	Max	3.0	—	4.8	4.8	6.0	10.0	4.0	10.0
	n	6	—	12	18	2	3	1	6
Total Phosphorus	$\overline{X}$	19.	—	20.	20.	5.37	4.19	7.53	5.21
	S	5.	—	6.	6.	1.16	1.03	3.20	1.70
	Min	11.	—	13.	11.	3.90	3.00	4.70	3.00
	Max	25.	—	30.	30.	7.30	5.60	11.00	11.00
	n	6	—	12	18	14	9	3	26
Total Nitrogen 1974 NO_2+NO_3 1980	$\overline{X}$	0.513	—	0.479	0.492	0.535	0.472	0.609	0.522
	S	0.056	—	0.039	0.047	0.125	0.055	0.183	0.117
	Min	0.450	—	0.404	0.404	0.430	0.378	0.402	0.378
	Max	0.610	—	0.532	0.610	0.927	0.525	0.749	0.927
	n	6	—	10	16	14	9	3	26

(continued)

Table B-1. Concluded.

Parameter		1974 Spring	1974 Summer	1974 Fall	1974 Annual	1980 Spring	1980 Summer	1980 Fall	1980 Annual
Reactive Silicate	$\bar{X}$	1.5	—	0.6	0.9	1.236	0.771	1.143	1.064
	S	0.2	—	0.1	0.1	0.263	0.128	0.208	0.299
	Min	1.3	—	0.5	0.5	0.600	0.620	1.120	0.600
	Max	1.6	—	0.7	1.6	1.530	0.910	1.160	1.530
	n	6	—	12	18	14	9	3	26
Chlorophyll	$\bar{X}$	1.4	—	1.0	1.1	2.82	1.09	1.60	2.08
	S	0.6	—	0.2	0.4	2.22	0.56	0.17	1.83
	Min	0.7	—	0.8	0.7	1.20	0.60	1.40	0.60
	Max	2.2	—	1.4	2.2	7.80	2.00	1.70	7.80
	n	5	—	12	17	14	9	3	26
Conductivity	$\bar{X}$	200	—	205	203	210.1	205.9	211.7	208.8
	S	3	—	1	2	7.9	5.7	2.3	7.0
	Min	196	—	204	196	203.0	198.0	209.0	198.0
	Max	204	—	206	206	228.0	211.0	213.0	228.0
	n	6	—	12	18	14	9	3	26
Chloride	$\bar{X}$	5.6	—	5.8	5.7	5.84	6.08	5.80	5.94
	S	0.3	—	0.1	0.2	0.28	0.20	0.10	0.25
	Min	3.4	—	5.6	3.4	5.50	5.80	5.70	5.50
	Max	6.2	—	6.0	6.2	6.40	6.50	5.90	6.50
	n	6	—	6	12	9	9	3	21
Sulfate	$\bar{X}$	16.2	—	15.3	15.6	16.26	16.44	15.90	16.29
	S	0.8	—	0.1	0.6	0.65	0.44	0.17	0.53
	Min	15.0	—	15.1	15.0	15.80	16.00	15.70	15.70
	Max	17.0	—	15.7	17.0	17.80	17.40	16.00	17.80
	n	6	—	6	12	9	9	3	21

Table B-2. 1974 and 1980 statistical summaries of nearshore area B epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

Parameter		1974				1980			
		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	8.1	—	14.1	—	6.0	19.4	10.2	11.3
	S	0.7	—	0.7	—	3.2	3.0	0.54	6.9
	Min	4.7	—	11.8	—	1.8	7.7	9.4	1.8
	Max	9.8	—	17.8	—	11.2	22.1	10.9	22.1
	n	29	—	48	—	31	21	7	59
Secchi Depth	$\overline{X}$	0.6	—	1.9	1.2	7.8	4.4	1.0	4.8
	S	0.4	—	1.2	0.9	6.7	2.4	—	3.6
	Min	0.1	—	0.4	0.1	3.0	1.5	1.0	1.0
	Max	1.5	—	3.5	3.5	12.5	7.0	1.0	12.5
	n	14	—	13	27	2	6	1	9
Total Phosphorus	$\overline{X}$	29.	—	17.	22.	7.28	5.19	8.50	6.67
	S	12.	—	6.	9.	2.56	1.31	3.13	2.53
	Min	9.	—	10.	9.	3.80	3.30	3.90	3.30
	Max	53.	—	31.	53.	13.00	8.10	11.90	13.00
	n	14	—	23	37	30	21	7	58
Total Nitrogen	$\overline{X}$	0.902	—	0.448	0.647	0.593	0.485	0.467	0.540
	S	0.250	—	0.047	0.168	0.157	0.078	0.044	0.135
	Min	0.375	—	0.382	0.375	0.380	0.365	0.396	0.365
	Max	1.35	—	0.553	1.35	0.990	0.616	0.516	0.990
	n	14		18	32	31	21	7	59

(continued)

Table B-2. Concluded.

Parameter		1974 Spring	 Summer	 Fall	 Annual	1980 Spring	 Summer	 Fall	 Annual
Reactive Silicate	$\overline{X}$	0.8	—	0.7	0.8	1.154	0.905	1.217	1.072
	S	0.2	—	0.1	0.2	0.280	0.234	0.090	0.276
	Min	0.5	—	0.7	0.5	0.510	0.510	1.100	0.510
	Max	1.0	—	1.1	1.1	1.500	1.550	1.330	1.550
	n	14	—	14	2.8	31	21	7	59
Chlorophyll	$\overline{X}$	4.1	—	0.8	2.5	3.17	1.13	1.94	2.30
	S	1.6	—	0.3	1.2	1.37	0.52	0.66	0.42
	Min	2.1	—	0.3	0.3	1.50	0.50	1.10	0.50
	Max	6.6	—	1.6	6.6	6.20	1.90	2.70	6.20
	n	14	—	14	28	31	21	7	59
Conductivity	$\overline{X}$	246	—	207	227	214.5	207.0	219.0	212.4
	S	4	—	1	3	8.6	13.1	8.1	11.1
	Min	212	—	206	206	204.0	188.0	203.0	188.0
	Max	348	—	214	348	232.0	250.0	228.0	250.0
	n	14	—	14	28	31	21	7	59
Chloride	$\overline{X}$	8.4	—	5.8	6.9	5.95	5.93	6.34	6.00
	S	2.3	—	0.4	1.5	0.51	0.22	0.42	0.41
	Min	5.9	—	5.5	5.5	5.00	5.60	5.90	5.00
	Max	14.6	—	6.9	14.6	7.10	6.50	7.00	7.10
	n	10	—	14	24	20	21	7	48
Sulfate	$\overline{X}$	20.2	—	15.6	17.5	16.68	16.32	16.99	16.57
	S	2.9	—	0.5	1.9	0.96	0.44	0.49	0.74
	Min	16.2	—	15.0	15.0	15.50	15.70	16.40	15.50
	Max	25.0	—	16.5	25.0	18.50	17.80	17.50	18.50
	n	10	—	14	24	20	21	7	48

Table B-3. 1974 and 1980 statistical summaries of nearshore area C epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

		1974				1980			
Parameter		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	7.0	—	13.1	—	5.8	17.8	9.4	10.9
	S	6.3	—	0.6	—	2.7	1.4	0.7	6.0
	Min	3.6	—	12.3	—	1.9	16.0	8.4	1.9
	Max	9.8	—	13.6	—	9.0	19.5	9.9	19.5
	n	46	—	6	—	15	12	4	31
Secchi Depth	$\overline{X}$	4.4	—	3.8	4.3	8.0	8.7	—	8.4
	S	2.1	—	0.3	2.0	2.8	1.2	—	1.7
	Min	1.0	—	3.5	1.0	6.0	8.0	—	6.0
	Max	10.0	—	4.0	10.0	10.0	10.0	—	10.0
	n	20	—	3	23	2	3	—	5
Total Phosphorus	$\overline{X}$	9	—	14	10	4.83	4.16	6.50	4.78
	S	5	—	8	5	0.12	0.38	1.11	1.17
	Min	4	—	8	4	3.60	3.70	5.20	3.60
	Max	32	—	43	43	8.60	5.00	7.90	8.60
	n	20	—	3	23	14	12	4	30
Total Nitrogen	$\overline{X}$	0.419	—	0.442	0.422	0.423	0.418	0.431	0.422
	S	0.005	—	0.044	0.014	0.055	0.021	0.065	0.044
	Min	0.322	—	0.412	0.322	0.370	0.380	0.391	0.370
	Max	0.545	—	0.492	0.545	0.563	0.448	0.528	0.563
	n	20	—	3	23	14	12	4	30

(continued)

Table B-3. Concluded.

Parameter		1974 Spring	1974 Summer	1974 Fall	1974 Annual	1980 Spring	1980 Summer	1980 Fall	1980 Annual
Reactive Silicate	$\overline{X}$	1.3	—	0.7	1.2	1.377	0.916	1.190	1.174
	S	0.1	—	0.3	0.1	0.147	0.132	0.271	0.252
	Min	0.7	—	0.6	0.6	1.140	0.680	1.170	0.680
	Max	1.1	—	1.8	1.8	1.500	1.050	1.230	1.500
	n	20	—	3	23	15	12	4	31
Chlorophyll	$\overline{X}$	0.7	—	0.7	0.7	2.17	1.20	1.32	1.67
	S	0.4	—	0.1	0.4	0.40	0.32	0.096	0.58
	Min	0.3	—	0.7	0.3	1.70	0.70	1.20	0.70
	Max	2.1	—	0.8	2.1	2.70	1.70	1.40	2.70
	n	20	—	3	23	14	12	4	30
Conductivity	$\overline{X}$	205	—	205	205	207.8	201.1	213.5	205.9
	S	7	—	2	7	4.6	5.3	1.3	6.2
	Min	192	—	204	192	203.0	191.0	212.0	191.0
	Max	224	—	206	224	217.0	207.0	215.0	217.0
	n	20	—	3	23	15	12	4	31
Chloride	$\overline{X}$	5.9	—	5.7	5.9	5.56	5.58	5.70	5.59
	S	0.2	—	0.1	0.2	0.13	0.26	0.08	0.19
	Min	5.3	—	5.6	5.3	5.40	5.20	5.60	5.20
	Max	6.1	—	5.8	6.1	5.80	5.90	5.80	5.90
	n	20	—	3	23	12	10	4	26
Sulfate	$\overline{X}$	15.6	—	15.0	15.5	15.95	15.60	16.12	15.84
	S	1.2	—	0	1.1	0.33	0.37	0.17	0.19
	Min	12.0	—	15.0	12.0	15.60	14.90	15.90	14.90
	Max	18.0	—	15.0	18.0	16.60	16.10	16.30	16.60
	n	20	—	3	23	12	10	4	26

Table B-4. 1974 and 1980 statistical summaries of nearshore area D epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

		1974				1980			
Parameter		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	5.6	8.7	—	—	3.6	16.9	8.1	9.6
	S	2.1	3.7	—	—	1.9	2.5	0.47	6.6
	Min	2.4	4.5	—	—	1.6	13.0	7.4	1.6
	Max	8.3	2.0	—	—	7.9	20.5	8.7	20.5
	n	132	150	—	—	19	17	6	42
Secchi Depth	$\overline{X}$	7.2	7.3	—	7.3	10.8	8.8	6.5	9.6
	S	1.3	1.8	—	1.6	2.4	3.0	0.71	2.8
	Min	3.5	3.5	—	3.5	8.0	4.0	6.0	4.0
	Max	10.5	9.6	—	10.5	16.0	11.0	7.0	16.0
	n	68	86	—	154	10	7	2	19
Total Phosphorus	$\overline{X}$	7	4	—	5	4.31	4.01	4.05	4.15
	S	7	3	—	5	1.27	0.79	0.64	1.01
	Min	3	1	—	1	3.30	2.90	3.30	2.90
	Max	20	14	—	20	8.10	6.30	4.80	8.10
	n	69	83	—	152	19	17	6	42
Total Nitrogen	$\overline{X}$	0.410	0.397	—	0.400	0.433	0.397	0.448	0.421
	S	0.130	0.058	—	0.082	0.070	0.024	0.017	0.053
	Min	0.230	0.292	—	0.230	0.374	0.357	0.421	0.357
	Max	0.540	0.551	—	0.551	0.654	0.446	0.471	0.654
	n	25	73	—	98	19	17	6	42

(continued)

Table B-4. Concluded.

Parameter		1974 Spring	 Summer	 Fall	 Annual	1980 Spring	 Summer	 Fall	 Annual
Reactive Silicate	$\overline{X}$	1.2	0.7	—	0.9	1.152	0.925	1.138	1.058
	S	0.1	0.1	—	0.1	0.773	0.068	0.106	0.135
	Min	0.9	0.6	—	0.6	0.990	0.820	1.020	0.820
	Max	1.5	0.9	—	1.5	1.270	1.020	1.270	1.270
	n	71	87	—	158	19	17	6	42
Chlorophyll	$\overline{X}$	0.7	1.0	--	0.9	1.08	1.05	1.10	1.07
	S	0.5	0.3	—	0.4	0.18	0.19	0.11	0.17
	Min	0.1	0.2	—	0.1	0.80	0.70	0.90	0.70
	Max	3.4	2.5	—	3.4	1.50	1.40	1.20	1.50
	n	70	82	—	152	19	17	6	42
Conductivity	$\overline{X}$	196	187	—	191	191.8	188.1	195.0	190.8
	S	8	12	—	10	2.5	6.7	1.3	5.2
	Min	190	163	—	163	189.0	181.0	194.0	181.0
	Max	206	198	—	206	198.0	203.0	197.0	203.0
	n	69	85	—	154	19	17	6	42
Chloride	$\overline{X}$	5.1	5.1	---	5.1	4.86	5.03	5.08	4.98
	S	0.3	0.2	—	0.2	0.17	0.19	0.12	0.19
	Min	4.6	4.0	—	4.0	4.40	4.80	4.90	4.40
	Max	5.7	6.0	—	6.0	5.10	5.40	5.20	5.40
	n	68	91	—	159	13	15	6	34
Sulfate	$\overline{X}$	15.2	15.7	--	15.5	15.10	15.25	15.47	15.23
	S	0.6	0.5	—	0.5	0.43	0.30	0.34	0.37
	Min	14.0	14.5	—	14.0	14.30	14.70	15.00	14.30
	Max	18.0	16.5	—	18.0	15.80	15.80	15.80	15.80
	n	63	86	—	149	13	15	6	34

Table B-5. 1974 and 1980 statistical summaries of nearshore area E epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

		1974				1980			
Parameter		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	13.0	16.1	7.9	—	7.6	16.6	7.4	10.9
	S	2.6	3.8	2.6	—	3.2	2.0	0.88	5.1
	Min	6.7	7.0	5.0	—	2.4	12.5	6.4	2.4
	Max	18.1	22.4	16.8	—	12.5	19.6	9.2	19.6
	n	79	127	29	—	52	38	13	103
Secchi Depth	$\overline{X}$	6.4	7.4	7.1	7.0	7.5	7.7	5.0	7.5
	S	1.3	1.9	0.7	1.6	2.4	2.0	4.2	2.3
	Min	3.5	5.8	3.0	3.0	2.5	4.0	2.0	2.0
	Max	8.0	8.8	8.0	8.8	11.0	11.0	8.0	11.0
	n	39	62	11	112	23	16	2	41
Total Phosphorus	$\overline{X}$	8	5	6	6	5.56	3.82	4.68	4.81
	S	4	1	2	3	2.29	1.03	0.54	1.92
	Min	4	3	3	3	2.80	2.30	4.00	2.30
	Max	21	8	20	21	15.30	7.10	5.80	15.30
	n	41	62	16	119	52	38	13	103
Total Nitrogen	$\overline{X}$	0.940	0.388	0.451	0.550	0.416	0.372	0.411	0.399
	S	0.330	0.107	0.099	0.193	0.053	0.025	0.035	0.047
	Min	0.370	0.141	0.176	0.041	0.327	0.448	0.355	0.327
	Max	1.34	1.01	0.583	1.34	0.558	0.333	0.479	0.558
	n	35	69	25	129	52	38	13	103

(continued)

Table B-5. Concluded.

Parameter		1974 Spring	Summer	Fall	Annual	1980 Spring	Summer	Fall	Annual
Reactive Silicate	$\overline{X}$	1.3	0.9	1.0	1.0	1.343	0.882	1.212	1.156
	S	0.3	0.2	0.1	0.2	0.314	0.127	0.091	0.319
	Min	0.9	0.6	0.7	0.6	0.990	0.640	1.090	0.640
	Max	4.9	1.0	2.1	4.9	2.430	1.100	1.320	2.430
	n	43	69	16	128	52	38	13	103
Chlorophyll	$\overline{X}$	1.2	1.0	0.7	1.0	1.70	1.33	1.29	1.51
	S	0.7	0.3	0.4	0.5	0.39	0.32	0.27	0.40
	Min	0.2	0.7	0.3	0.2	1.10	0.90	0.80	0.80
	Max	2.7	1.6	1.9	2.7	2.40	2.10	1.60	2.40
	n	39	62	15	116	52	38	13	103
Conductivity	$\overline{X}$	164	179	180	174	170.6	179.2	193.8	176.7
	S	14	3	13	9	21.1	5.6	2.7	17.1
	Min	143	135	150	135	106.0	168.0	188.0	106.0
	Max	180	184	198	198	192.0	189.0	198.0	198.0
	n	43	71	16	130	52	38	13	103
Chloride	$\overline{X}$	4.9	4.7	4.8	4.8	4.50	4.71	4.97	4.66
	S	0.5	0.3	0.3	0.4	0.46	0.17	0.63	0.36
	Min	4.0	4.2	2.6	2.6	3.40	4.30	4.90	3.40
	Max	6.5	5.9	5.4	6.5	5.20	5.00	5.10	5.20
	n	68	91	39	198	33	32	13	78
Sulfate	$\overline{X}$	13.4	15.3	15.9	14.7	14.86	15.01	15.50	15.03
	S	2.4	1.3	1.1	1.7	0.63	0.25	0.24	0.50
	Min	1.0	14.0	14.0	1.0	13.20	14.40	14.90	13.20
	Max	17.0	18.0	16.0	18.0	15.90	15.60	15.80	15.90
	n	43	69	16	128	33	32	13	78

Table B-6. 1974 and 1980 statistical summaries of nearshore area F epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

Parameter		1974				1980			
		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	13.4	16.5	8.1	—	7.7	16.3	7.6	11.4
	S	2.1	4.3	1.6	—	3.6	3.1	0.52	5.3
	Min	8.5	9.2	5.9	—	2.0	9.5	7.0	2.0
	Max	17.9	22.5	17.5	—	13.5	20.7	8.4	20.7
	n	91	166	53	—	35	35	11	81
Secchi Depth	$\overline{X}$	4.1	4.6	4.4	4.4	5.3	6.9	3.1	5.3
	S	2.0	1.6	1.5	1.7	2.0	1.5	1.2	2.2
	Min	1.0	2.3	1.5	1.0	1.0	4.0	1.0	1.0
	Max	7.0	7.7	8.0	8.0	9.0	8.0	4.5	9.0
	n	60	83	26	169	18	12	9	39
Total Phosphorus	$\overline{X}$	12	14	12	13	5.78	5.54	5.84	5.68
	S	8	2	8	6	0.19	2.42	0.67	2.01
	Min	3	2	2	2	3.80	3.40	4.80	3.40
	Max	31	100	36	100	12.40	17.40	7.10	17.40
	n	59	83	26	168	31	35	11	77
Total Nitrogen	$\overline{X}$	0.520	0.225	0.262	0.358	0.422	0.413	0.441	0.422
	S	0.043	0.045	0.072	0.047	0.077	0.035	0.057	0.058
	Min	0.360	0.171	0.193	0.171	0.326	0.334	0.384	0.326
	Max	0.630	0.398	0.393	0.630	0.628	0.499	0.580	0.628
	n	45	49	8	102	31	35	11	77

(continued)

Table B-6. Concluded.

Parameter		1974 Spring	Summer	Fall	Annual	1980 Spring	Summer	Fall	Annual
Reactive Silicate	$\overline{X}$	2.1	1.8	1.9	1.9	2.043	1.566	1.798	1.804
	S	0.4	0.2	0.3	0.3	0.311	0.131	0.106	0.315
	Min	1.6	1.2	1.5	1.2	1.470	1.320	1.590	1.320
	Max	3.3	2.1	2.1	3.3	2.680	1.850	1.940	2.680
	n	60	60	26	146	35	35	11	81
Chlorophyll	$\overline{X}$	0.6	1.1	1.6	1.0	2.01	1.41	2.05	1.74
	S	0.3	0.6	0.7	0.5	0.37	0.34	0.34	0.46
	Min	0.4	0.4	0.6	0.4	1.20	1.00	1.60	1.00
	Max	1.4	2.6	2.7	2.7	2.70	2.20	2.60	2.70
	n	60	83	26	169	31	35	11	77
Conductivity	$\overline{X}$	174	146	145	156	151.4	155.1	165.8	155.0
	S	10	25	24	21	19.4	6.0	12.9	14.8
	Min	79	103	100	79	95.0	137.0	140.0	95.0
	Max	180	180	180	180	168.0	164.0	185.0	185.0
	n	80	83	70	163	35	35	11	81
Chloride	$\overline{X}$	4.3	4.4	39	4.3	4.04	4.11	4.00	4.06
	S	0.8	0.6	1.0	0.7	0.74	0.35	0.65	0.59
	Min	1.9	2.8	1.6	1.6	1.80	3.10	3.00	1.80
	Max	5.5	5.0	5.0	5.5	4.70	4.60	4.70	4.70
	n	60	83	26	169	29	27	11	67
Sulfate	$\overline{X}$	12.5	13.2	12.8	12.9	13.34	13.02	12.93	13.14
	S	3.7	3.4	3.4	3.5	3.28	1.66	2.01	2.51
	Min	4.0	6.6	4.0	4.0	4.50	8.70	10.00	4.50
	Max	18.0	18.3	16.0	18.3	17.40	16.60	15.00	17.40
	n	60	83	26	169	29	27	11	67

Table B-7. 1974 and 1980 statistical summaries of nearshore area G epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

Parameter		1974				1980			
		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	13.1	—	15.1	—	5.6	17.0	7.4	9.6
	S	1.8	—	0.3	—	3.1	2.9	0.53	6.0
	Min	9.0	—	14.8	—	1.7	7.1	6.4	1.6
	Max	16.0	—	15.6	—	12.3	20.9	8.0	20.9
	n	20	—	20	—	42	25	9	76
Secchi Depth	$\overline{X}$	7.1	—	6.8	6.9	6.7	6.1	3.5	6.0
	S	0.5	—	0.8	0.7	1.9	1.2	0.71	1.9
	Min	6.4	—	6.4	6.4	4.5	4.5	3.0	3.0
	Max	7.6	—	10.1	10.1	9.5	7.5	4.0	9.5
	n	6	—	6	12	6	4	2	12
Total Phosphorus	$\overline{X}$	6	—	3	5	5.08	4.65	5.11	4.94
	S	6	—	2	4	1.10	1.26	0.58	1.12
	Min	2	—	2	2	3.50	3.10	4.30	3.10
	Max	23	—	8	23	9.50	8.00	6.00	9.50
	n	21	—	20	41	42	25	9	76
Total Nitrogen	$\overline{X}$	0.362	—	0.353	0.358	0.420	0.397	0.414	0.412
	S	0.080	—	0.047	0.066	0.063	0.054	0.047	0.058
	Min	0.292	—	0.297	0.292	0.323	0.322	0.360	0.322
	Max	0.622	—	0.482	0.622	0.674	0.537	0.526	0.674
	n	21	—	20	41	42	25	9	76

(continued)

Table B-7. Concluded.

		1974				1980			
Parameter		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Reactive Silica	$\overline{X}$	1.2	—	0.8	1.0	1.421	0.926	1.111	1.030
	S	0.3	—	0.1	0.2	0.109	0.232	0.195	0.207
	Min	1.0	—	0.8	0.8	1.120	0.560	0.890	0.670
	Max	1.6	—	0.9	1.6	1.500	1.390	1.430	1.480
	n	6	—	6	12	42	25	9	88
Chlorophyll	$\overline{X}$	1.7	—	2.1	1.9	1.98	1.46	2.03	2.41
	S	0.3	—	0.2	0.3	0.63	0.66	0.56	1.66
	Min	1.4	—	1.9	1.4	1.40	0.70	1.80	0.90
	Max	2.1	—	2.3	2.3	3.80	3.00	2.40	10.00
	n	3	—	3	6	42	25	9	90
Conductivity	$\overline{X}$	191	—	185	188	208.8	195.4	214.9	205.1
	S	6	—	2	4	6.2	7.4	7.4	9.8
	Min	184	—	183	183	203.0	186.0	208.0	186.0
	Max	204	—	189	204	228.0	213.0	232.0	232.0
	n	20	—	20	40	42	25	9	76
Chloride	$\overline{X}$	4.8	—	5.7	5.3	5.48	5.34	5.64	5.45
	S	0.2	—	0.1	0.2	0.17	0.30	0.32	0.27
	Min	4.6	—	5.6	4.6	5.20	4.80	5.40	4.80
	Max	5.0	—	5.9	5.9	5.90	5.70	6.40	6.40
	n	6	—	6	12	27	22	9	58
Sulfate	$\overline{X}$	13.7	—	12.7	13.2	16.17	14.84	15.78	15.60
	S	0.6	—	0.6	0.6	0.54	0.81	0.67	0.91
	Min	13.0	—	12.0	12.0	14.90	13.30	15.30	13.30
	Max	14.0	—	13.0	14.0	17.50	16.00	17.20	17.50
	n	6	—	6	12	27	22	9	58

Table B-8. 1974 and 1980 statistical summaries of nearshore area I epilimnetic waters of Lake Huron-Georgian Bay-North Channel (depth 1-10 meters).

Parameter		1974				1980			
		Spring	Summer	Fall	Annual	Spring	Summer	Fall	Annual
Temperature	$\overline{X}$	13.6	--	19.2	--	6.4	18.2	10.2	10.8
	S	1.4	--	0.5	--	2.7	2.6	0.37	6.0
	Min	11.0	--	18.0	--	1.7	11.6	9.7	1.7
	Max	16.5	--	18.9	--	11.9	22.0	10.8	22.0
	n	40	--	40	--	51	31	8	90
Secchi Depth	$\overline{X}$	4.7	--	5.3	5.0	5.2	7.4	2.9	5.4
	S	0.8	--	1.1	1.0	1.2	2.0	0.7	2.4
	Min	2.4	--	3.0	2.4	3.5	4.5	2.0	2.0
	Max	8.2	--	7.3	8.2	7.0	10.5	4.0	10.5
	n	12	--	12	24	8	9	7	24
Total Phosphorus	$\overline{X}$	8	--	6	7	6.24	5.31	6.94	6.00
	S	5	--	3	4	2.23	2.24	0.90	2.20
	Min	2	--	2	2	3.50	3.00	6.10	3.00
	Max	24	--	12	24	13.70	14.40	8.80	14.40
	n	40	--	40	80	51	29	8	88
Total Nitrogen	$\overline{X}$	0.417	--	0.473	0.445	0.474	0.421	0.472	0.456
	S	0.086	--	0.047	0.069	0.077	0.041	0.029	0.068
	Min	0.301	--	0.402	0.301	0.365	0.360	0.422	0.360
	Max	0.716	--	0.572	0.716	0.701	0.538	0.514	0.701
	n	40	--	40	80	51	29	8	88

(continued)

Table B-8. Concluded.

Parameter		1974 Spring	1974 Summer	1974 Fall	1974 Annual	1980 Spring	1980 Summer	1980 Fall	1980 Annual
Reactive Silica	$\overline{X}$	0.9	—	0.8	0.8	1.116	0.904	0.942	1.038
	S	0.4	—	0.2	0.3	0.222	0.094	0.143	0.207
	Min	0.5	—	0.4	0.4	0.670	0.700	0.760	0.670
	Max	1.8	—	0.8	1.8	1.480	1.050	1.190	1.480
	n	12	—	12	24	51	29	8	88
Chlorophyll	$\overline{X}$	2.5	—	4.7	3.7	2.81	1.50	3.42	2.41
	S	0.4	—	1.7	1.3	1.97	0.94	0.81	1.66
	Min	1.9	—	2.9	1.9	1.30	0.90	2.50	0.90
	Max	3.1	—	7.7	7.7	10.00	2.50	4.70	10.00
	n	5	—	6	11	51	31	8	90
Conductivity	$\overline{X}$	198	—	190	194	213.3	200.9	213.4	209.0
	S	11	—	1	8	8.6	9.1	2.7	10.3
	Min	181	—	88	181	202.0	184.0	211.0	184.0
	Max	227	—	227	227	235.0	217.0	219.0	235.0
	n	40	—	40	80	51	31	8	90
Chloride	$\overline{X}$	6.1	—	5.7	5.9	6.28	5.87	5.91	6.07
	S	0.9	—	0.1	0.6	1.01	0.38	0.16	0.76
	Min	5.0	—	5.6	5.0	5.20	5.40	5.70	5.20
	Max	7.1	—	5.8	7.1	8.90	7.00	6.20	8.90
	n	12	—	12	24	33	29	8	70
Sulfate	$\overline{X}$	15.6	—	14.2	14.9	16.62	15.91	15.82	16.24
	S	1.7	—	0.9	1.4	0.97	0.66	0.32	0.87
	Min	14.0	—	13.0	13.0	15.60	15.20	15.40	15.20
	Max	18.0	—	15.0	18.0	18.90	17.40	16.30	18.90
	n	12	—	12	24	33	29	8	70

Table B-9. 1974 and 1980 statistical summaries of open lake areas epilimnetic waters of Lake Huron-Georgian Bay-North Channel min and max observation-mean of all cruises. (epilimnion or 1-10 m depth).

Parameter	1974				1980			
	Mean	Max	Min	N	Mean	Max	Min	N
Area 1 WNC								
1. Total P	7.7	8.8	6.5	6	6.3	8.2	4.8	6
2. Reactive SiO_2	2.10	2.31	1.97	6	1.89	2.10	1.70	6
3. Filtered NO_3+NO_2*	0.26	0.29	0.24	6	0.274	0.290	0.237	6
4. Chloride	2.6	3.0	2.3	6	3.3	4.1	2.9	5
5. Conductivity	130	142	122	6	141	171.0	126	6
Area 2 CNC								
1. Total P	5.3	6.5	4.0	6	5.0	5.6	4.2	6
2. Reactive SiO_2	1.94	2.37	1.58	6	1.84	2.16	1.49	6
3. Filtered NO_3+NO_2*	0.27	0.29	0.24	6	0.278	0.299	0.254	6
4. Chloride	4.4	4.7	4.1	6	4.4	4.5	4.1	5
5. Conductivity	165	173	155	6	163.5	177.5	155.4	6
Area 3a ENC								
1. Total P	5.9	7.1	5.0	6	5.5	6.7	4.7	5
2. Reactive SiO_2	1.88	2.17	1.48	6	1.65	1.95	1.43	5
3. Filtered NO_3+NO_2*	0.24	0.28	0.22	6	0.221	0.233	0.211	5
4. Chloride	4.6	4.6	4.5	6	4.4	4.5	4.1	5
5. Conductivity	167	176	160	6	165.9	176.7	157.7	5

*Total nitrogen in 1974

(continued)

Table B-9. Concluded.

Parameter	1974 Mean	Max	Min	N	1980 Mean	Max	Min	N
Area 4 A4LH								
1. Total P	5.7	8.2	3.5	8	5.1	6.1	4.7	6
2. Reactive SiO_2	1.65	2.25	0.96	8	1.46	1.66	0.90	6
3. Filtered NO_3+NO_2*	0.261	0.293	0.198	8	0.260	0.293	0.204	6
4. Chloride	4.7	5.6	3.9	8	4.6	5.4	4.3	5
5. Conductivity	180	202	154	8	179.4	206.6	138.6	6
Area 5 A5LH								
1. Total P	5.6	7.5	4.9	7	5.6	7.8	4.7	6
2. Reactive SiO_2	1.18	2.14	0.58	7	1.11	1.29	0.64	6
3. Filtered NO_3+NO_2*	0.192	0.260	0.140	7	0.216	0.242	0.179	6
4. Chloride	6.5	7.0	5.7	7	6.32	6.73	5.85	5
5. Conductivity	238	251	209	7	228.5	240.9	212.5	6
Area 6 NBLH								
1. Total P	4.8	7.7	2.4	13	4.6	5.1	4.4	6
2. Reactive SiO_2	1.37	1.99	0.99	13	1.33	1.55	0.90	6
3. Filtered NO_3+NO_2*	0.266	0.322	0.142	13	0.277	0.298	0.238	6
4. Chloride	5.4	5.7	4.0	13	5.4	5.5	5.2	5
5. Conductivity	201	219	193	13	201.0	209.8	191.6	6
Area 7 SBM								
1. Total P	5.6	10.2	2.7	15	4.5	4.9	3.6	6
2. Reactive SiO_2	1.20	2.12	0.69	15	1.19	1.53	0.90	6
3. Filtered NO_3+NO_2*	0.270	0.344	0.207	15	0.263	0.289	0.220	6
4 Chloride	6.0	7.3	5.5	15	5.7	6.2	5.3	5
5. Conductivity	208	224	188	14	204.9	214.6	189.8	6

*Total nitrogen in 1974

Table B-10. 1974 and 1980 statistical summaries of open lake areas epilimnetic waters of Lake Huron-Georgian Bay-North Channel.

Parameter	1974 Mean	1974 Max	1974 Min	1974 N	1980 Mean	1980 Max	1980 Min	1980 N
Area 8 SBLH								
1. Total P	5.3	8.7	3.6	15	4.2	4.9	3.7	8
2. Reactive SiO_2	1.18	2.14	0.58	15	1.32	1.59	0.89	8
3. Filtered NO_3+NO_2*	0.276	0.378	0.186	15	0.272	0.301	0.240	6
4. Chloride	5.8	6.3	4.9	15	5.6	6.0	5.5	7
5. Conductivity	206	222	194	14	205.7	213.4	197.1	8
Area 9								
1. Total P	5.4	9.6	3.3	8	4.2	4.9	3.6	6
2. Reactive SiO_2	1.18	1.91	0.66	8	1.23	1.42	0.96	6
3. Filtered NO_3+NO_2*	0.268	0.331	0.230	5	0.265	0.283	0.247	6
4. Chloride	5.5	5.8	5.2	8	5.4	5.5	5.4	5
5. Conductivity	197	212	182	8	202.9	207.4	196.0	6
Area 10 (*all depths used cruises 1-3)								
1. Total P	5.1	8.3	3.2	7	3.8	4.3	3.8	6
2. Reactive SiO_2	1.09	1.46	0.94	7	1.14	1.34	0.98	6
3. Filtered NO_3+NO_2*	0.24	0.28	0.20	7	0.254	0.285	0.202	6
4. Chloride	4.8	5.0	4.8	7	4.9	5.1	4.6	5
5. Conductivity	185	193	181	7	189.0	194.0	181.0	6

*Total nitrogen in 1974

(continued)

Table B-10. Concluded.

Parameter	1974 Mean	1974 Max	1974 Min	1974 N	1980 Mean	1980 Max	1980 Min	1980 N
Area 11								
1. Total P	5.0	9.4	3.6	7	3.9	4.0	3.7	6
2. Reactive SiO_2	1.03	1.41	0.89	7	1.12	1.28	0.91	6
3. Filtered NO_3+NO_2*	0.25	0.28	0.23	7	0.265	0.282	0.243	6
4. Chloride	5.0	5.2	4.8	7	5.1	5.3	4.8	5
5. Conductivity	190	199	185	7	191.5	197.0	183.5	6
Area 12								
1. Total P	4.8	7.9	3.0	7	4.0	5.3	3.9	6
2. Reactive SiO_2	1.14	1.43	0.80	7	1.10	1.18	0.89	6
3. Filtered NO_3+NO_2*	0.25	0.30	0.21	7	0.266	0.283	0.241	6
4. Chloride	4.9	5.0	4.8	7	4.9	5.2	4.7	5
5. Conductivity	189	201	185	7	189.5	197.2	181.5	6
Area 13								
1. Total P	4.7	7.1	3.2	7	4.5	5.1	4.0	6
2. Reactive SiO_2	1.12	1.46	1.19	7	1.05	1.18	0.87	6
3. Filtered NO_3+NO_2*	0.24	0.30	0.22	7	0.263	0.282	0.238	6
4. Chloride	4.8	5.0	4.8	7	5.0	5.1	4.8	5
5. Conductivity	188	193	184	7	190.2	194.7	183.3	6
Area 14								
1. Total P	5.0	7.3	3.6	7	4.2	4.5	3.7	6
2. Reactive SiO_2	1.04	1.22	0.82	7	1.03	1.33	0.82	6
3. Filtered NO_3+NO_2*	0.23	0.28	0.21	7	0.262	0.283	0.232	6
4. Chloride	4.9	5.0	4.7	7	4.9	4.0	4.8	5
5. Conductivity	188	196	184	7	190.2	198.1	180.4	6

*Total nitrogen in 1974

Table B-11. 1974 and 1980 statistical summaries of open lake areas epilimnetic waters of Lake Huron-Georgian Bay-North Channel min and max observation-mean of all cruises. (epilimnion or 1-10 m depth).

	1974				1980			
Parameter	Mean	Max	Min	N	Mean	Max	Min	N
			Area 15					
1. Total P	5.5	9.5	3.3	7	5.1	7.4	4.0	6
2. Reactive SiO_2	1.08	1.97	0.81	7	1.09	1.51	0.79	6
3. Filtered NO_3+NO_2*	0.22	0.27	0.19	7	0.235	0.274	0.217	6
4. Chloride	4.9	4.9	4.8	7	5.1	5.3	5.0	5
5. Conductivity	187	198	183	7	183.7	193.4	172.0	6
			Area 16					
1. Total P	4.7	7.6	3.3	7	4.6	7.5	3.6	6
2. Reactive SiO_2	1.11	1.44	0.82	7	1.02	1.19	0.88	6
3. Filtered NO_3+NO_2*	0.22	0.27	0.19	7	0.245	0.271	0.227	6
4. Chloride	4.7	4.8	4.6	7	4.7	5.0	4.5	5
5. Conductivity	182	185	177	7	182.4	192.5	174.4	6
			Area 17					
1. Total P	4.7	7.9	2.8	7	4.1	4.7	3.5	6
2. Reactive SiO_2	1.15	1.41	0.78	7	1.09	1.25	0.85	6
3. Filtered NO_3+NO_2*	0.24	0.28	0.20	7	0.260	0.277	0.232	6
4. Chloride	4.8	4.9	4.6	7	4.9	5.0	4.8	5
5. Conductivity	185	193	175	7	187.0	193.7	178.8	6

*Total nitrogen in 1974

(continued)

Table B-11. Concluded.

Parameter	1974 Mean	 Max	 Min	 N	1980 Mean	 Max	 Min	 N
Area 18								
1. Total P	5.7	9.7	3.8	7	5.3	7.3	2.8	6
2. Reactive SiO_2	1.24	1.52	0.94	7	1.32	1.70	0.98	6
3. Filtered NO_3+NO_2*	0.23	0.27	0.20	7	0.235	0.273	0.215	6
4. Chloride	4.6	4.8	4.4	7	4.6	5.0	4.4	5
5. Conductivity	178	182	171	7	169.9	195.2	154.1	6
Area 3								
1. Total P	5.6	9.3	3.3	7	4.3	5.0	3.6	6
2. Reactive SiO_2	1.33	1.63	1.02	7	1.24	1.43	1.00	6
3. Filtered NO_3+NO_2*	0.21	0.27	0.17	7	0.218	0.249	0.178	6
4. Chloride	4.7	4.9	4.4	7	4.9	5.1	4.7	5
5. Conductivity	182	188	177	7	185.4	194.3	176.3	6
Area-River								
1. Total P					8.9	10.6	7.1	6
2. Reactive SiO_2					2.16	2.23	2.10	6
3. Filtered NO_3+NO_2*					0.254	0.278	0.226	6
4. Chloride					1.4	1.4	1.3	5
5. Conductivity					97.4	101.0	91.3	6

*Total nitrogen in 1974
Areas number based on open water segmentation 1974 Figure